A WIRE IN THE AIR

what matters most

Kristen A. McIntyre
K6WX

MYSTERIOUS

- What is an Antenna?
- How does it work?
- Designs aren’t intuitive
- Maxwell’s Equations involved
  - complex calculations
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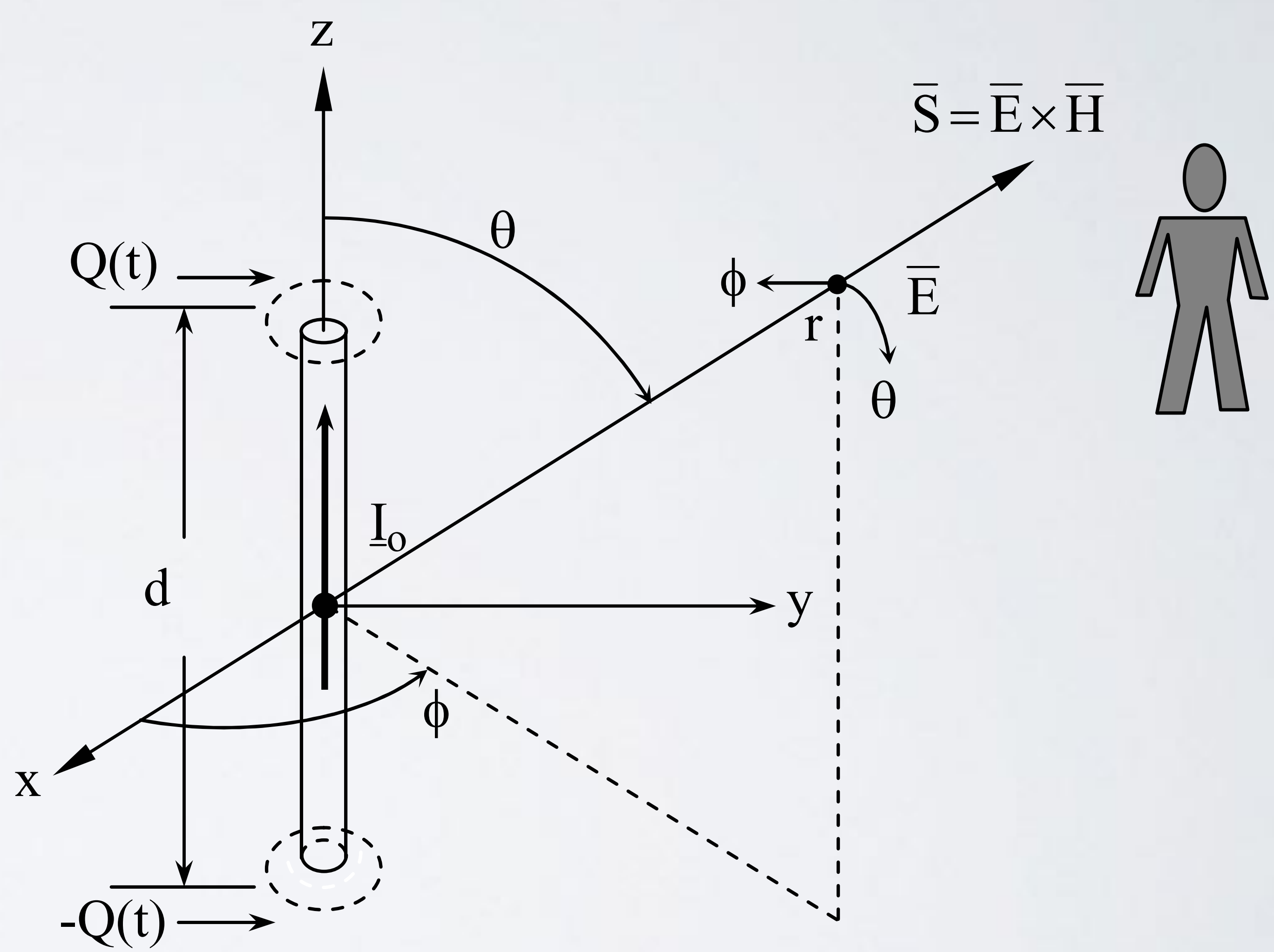

DEMYSTIFY

- Don’t care about everything
- Some things are important
  - but what?
- Many antennas are variants
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- Simple models
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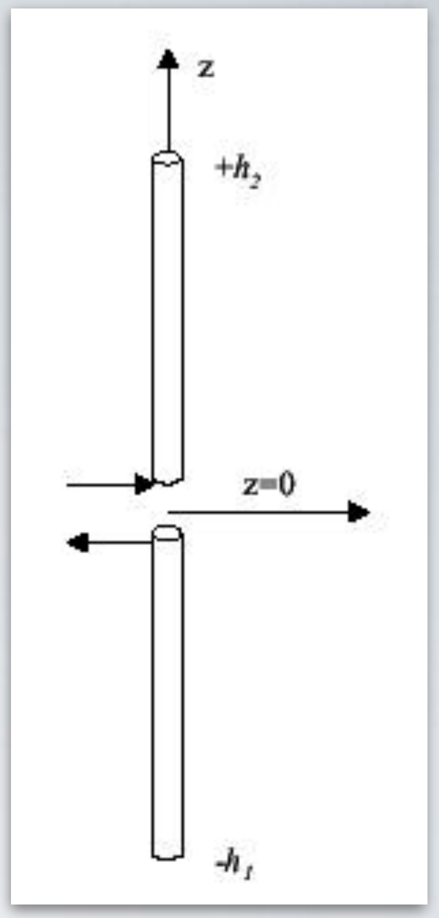

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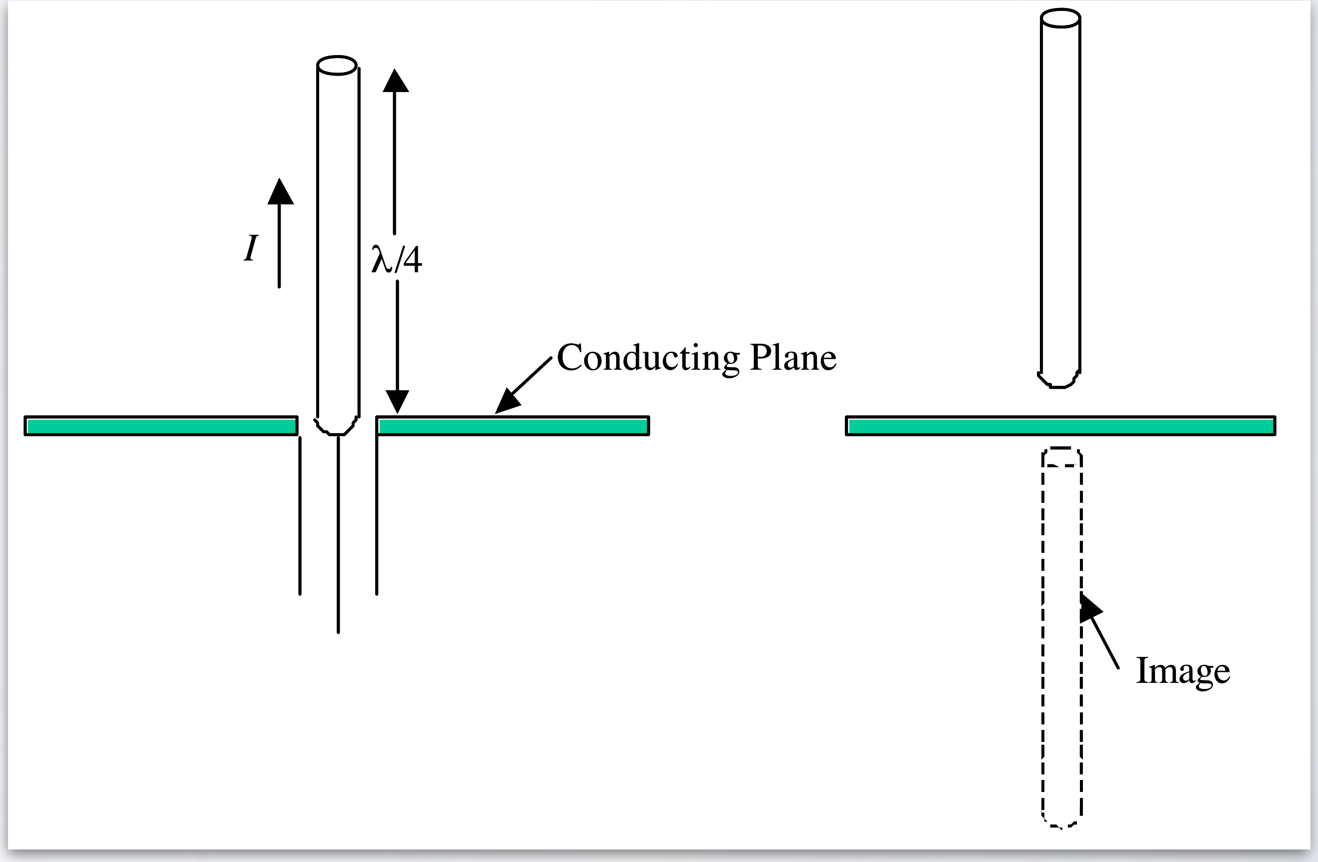

DIPOLE CALCULATION

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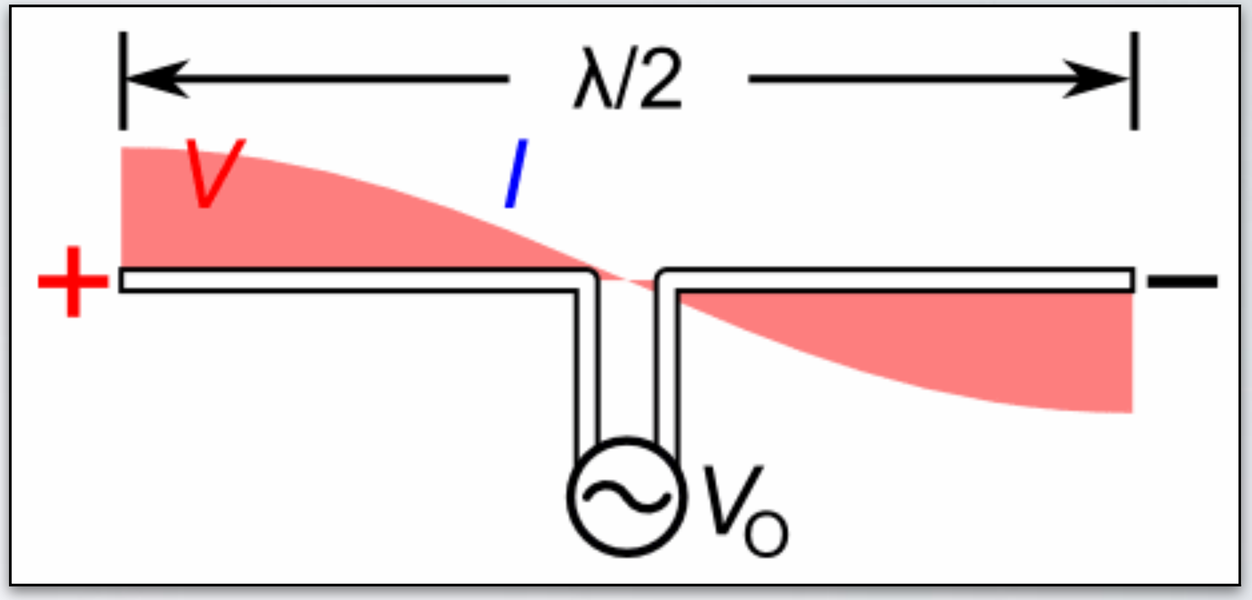

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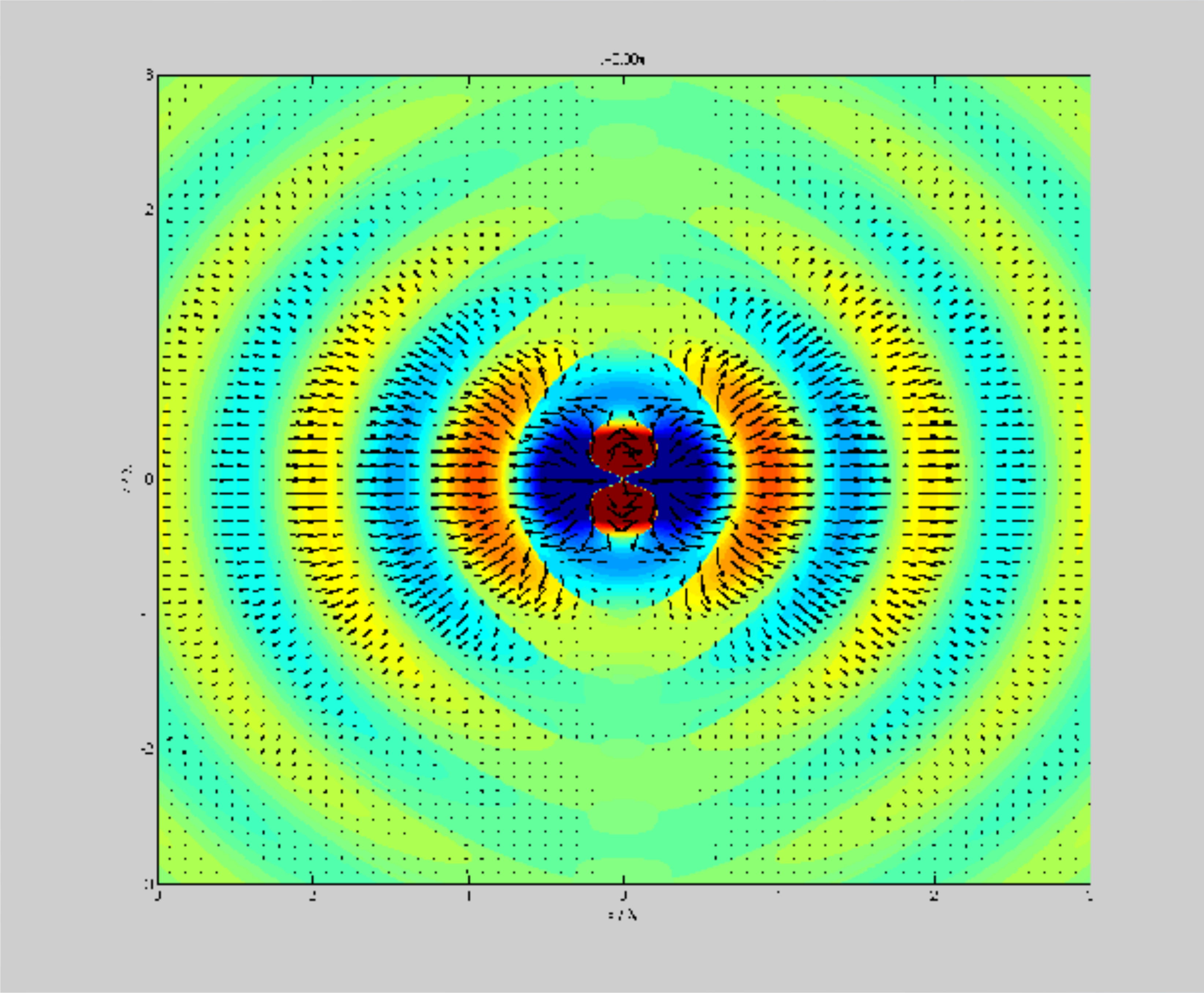
$$\frac{\partial^2 E}{\partial t^2} = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} \nabla^2 E$$

$$\frac{\partial^2 H}{\partial t^2} = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} \nabla^2 H$$

$$Z_0 = \frac{E}{H} = \sqrt{\frac{\mu_0}{\varepsilon_0}}$$

WHERE IS THE ENERGY?

- Interesting question
  - negligible resistance
- In the fields
- Does it return?
  - reactive
- Does it leave?
  - resistive



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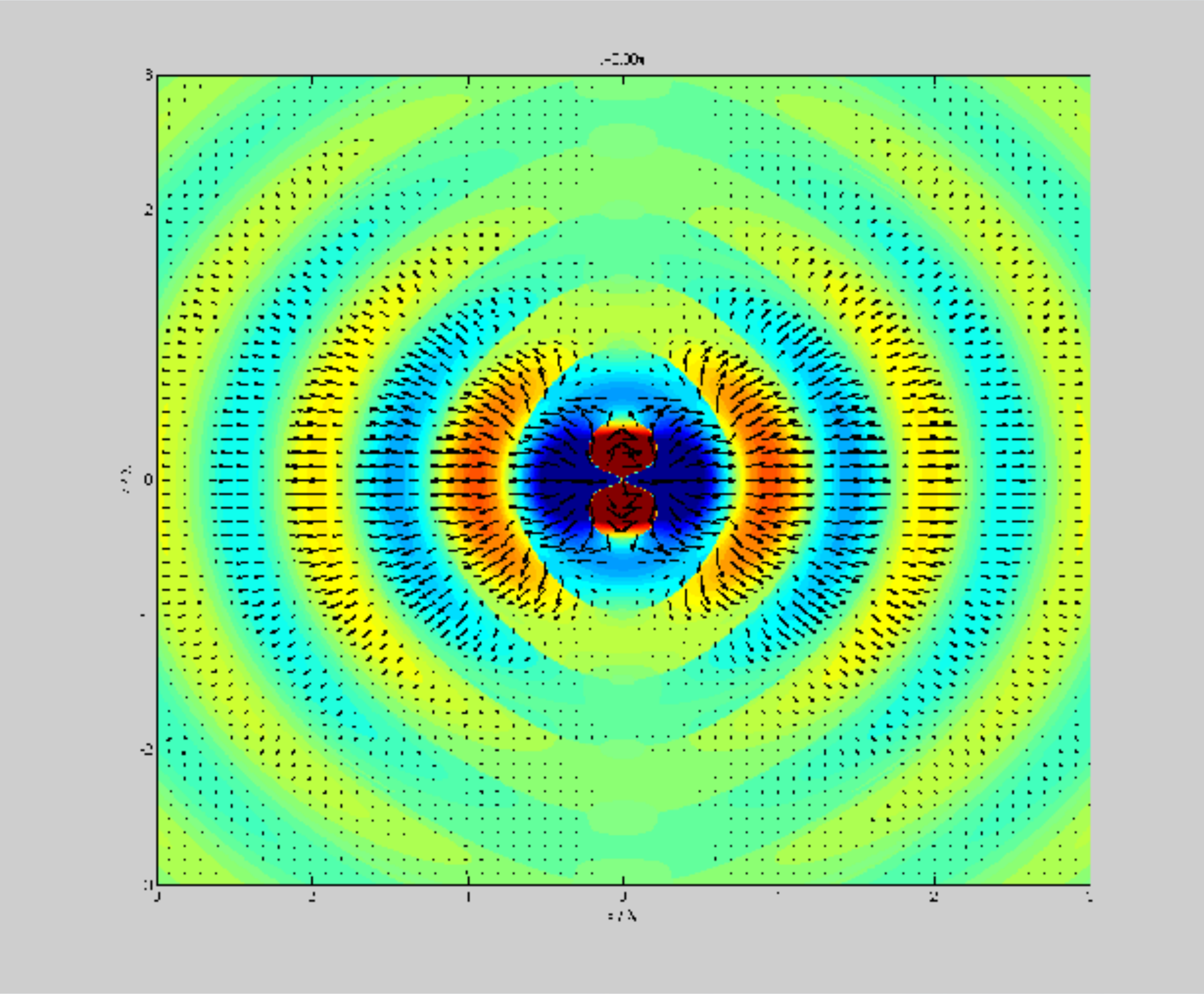

RADIATION RESISTANCE

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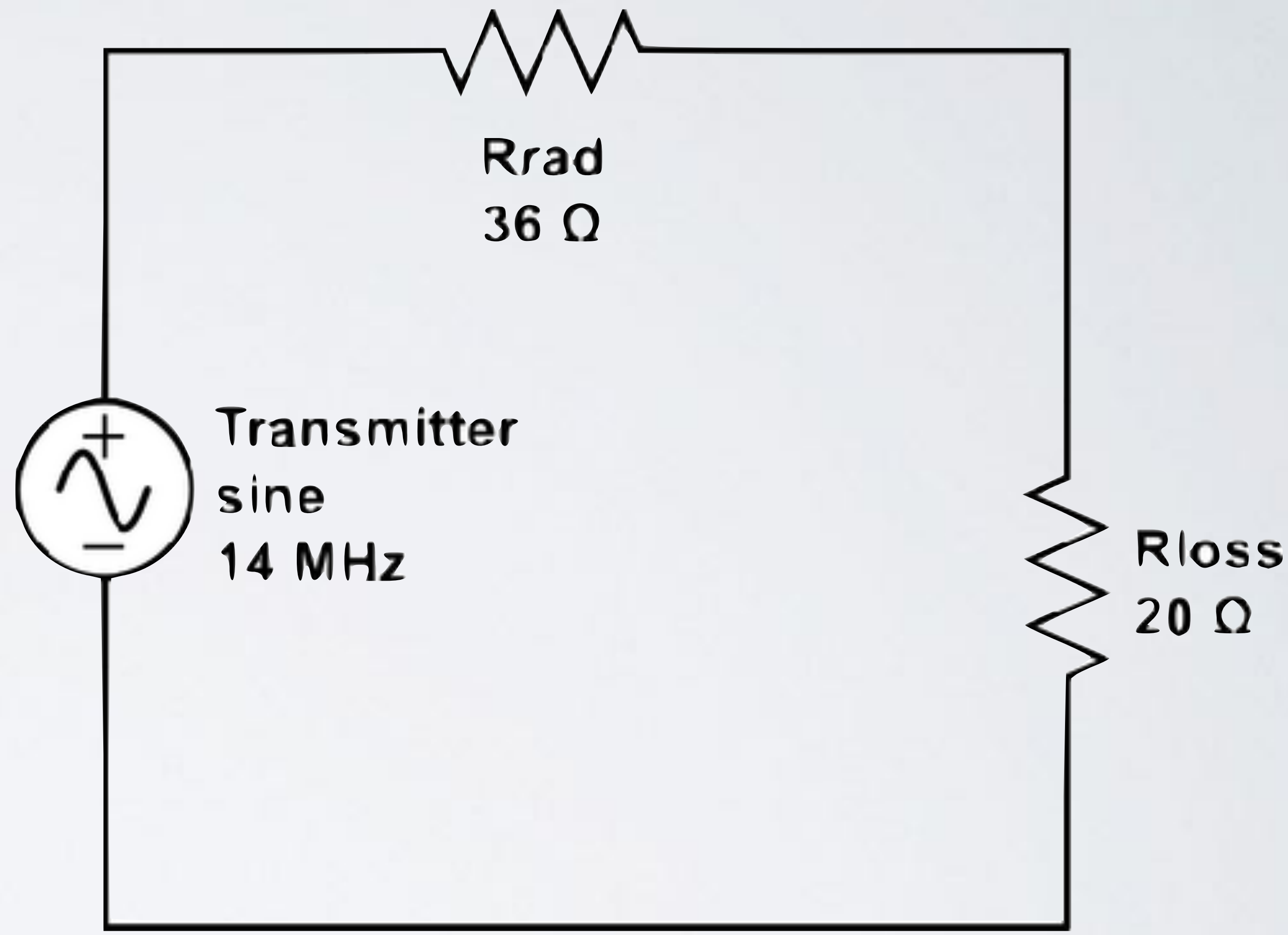

$$Eff_{power} = \frac{R_{rad}}{R_{rad}+R_{loss}} = \frac{36}{36+20} \cong 0.64$$

SPEAKERS BEHAVE SIMILARLY

- If purely reactive, everything returns
- Speakers do work on the air
    - F • d = Work=KE
    - conservation of energy
    - appears resistive

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MORE DIPOLE CALCULATION

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  - From power (Poynting)
  - Z_0 ratio of permeability / permittivity
- Integrate E/H across length
  - assume $L = 2\lambda$, $r \ll \lambda$
  - gives us ~72Ω
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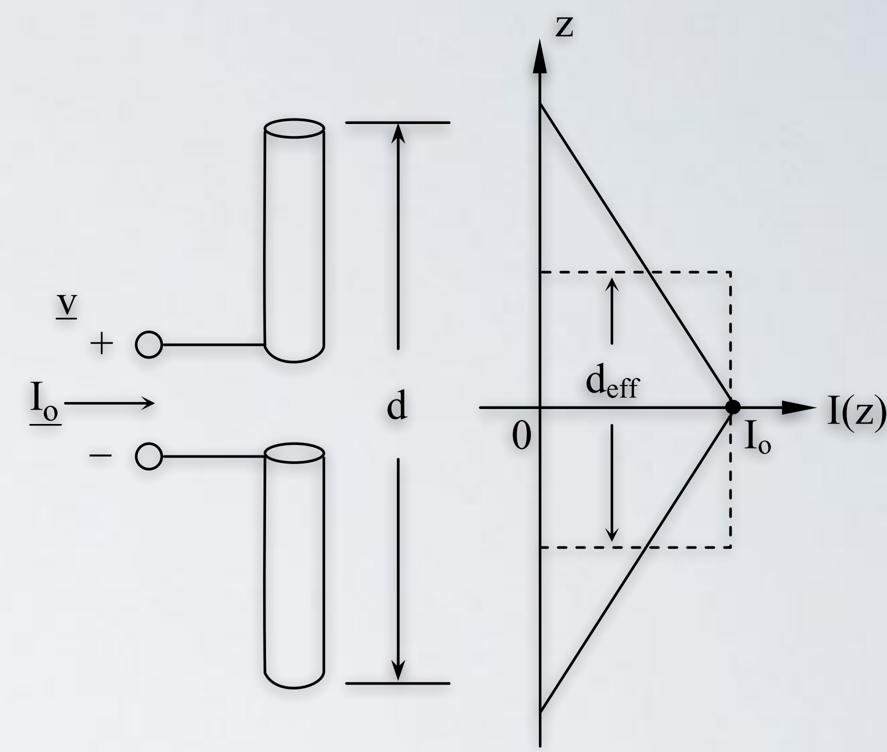
$$P_{avg} = \frac{I^2 R_{rad}}{2}$$



$$P = \oiint S\,ds = \frac{Z_0}{2}\int_0^{2\pi}\int_0^{\pi} |H_\phi|^2\ r^2 sin\theta\, d\theta\, d\phi$$

$$R_{rad} = \frac{Z_0}{\pi}\int_0^{\pi/2} |H_\phi|^2\, d\theta$$

POYNTING VECTOR

- $S = E \times H$
- A vector representing energy flow
- Same for DC circuits
  - energy outside the wires
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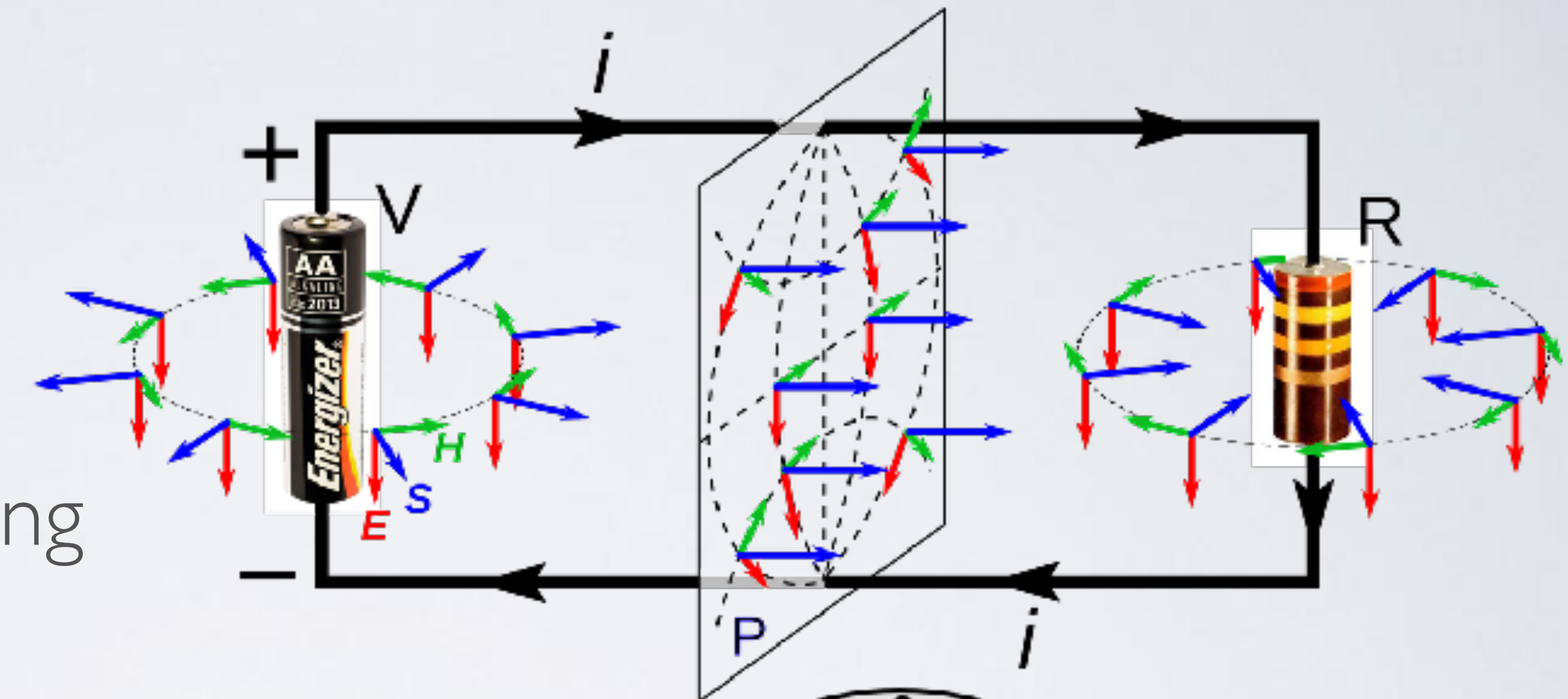

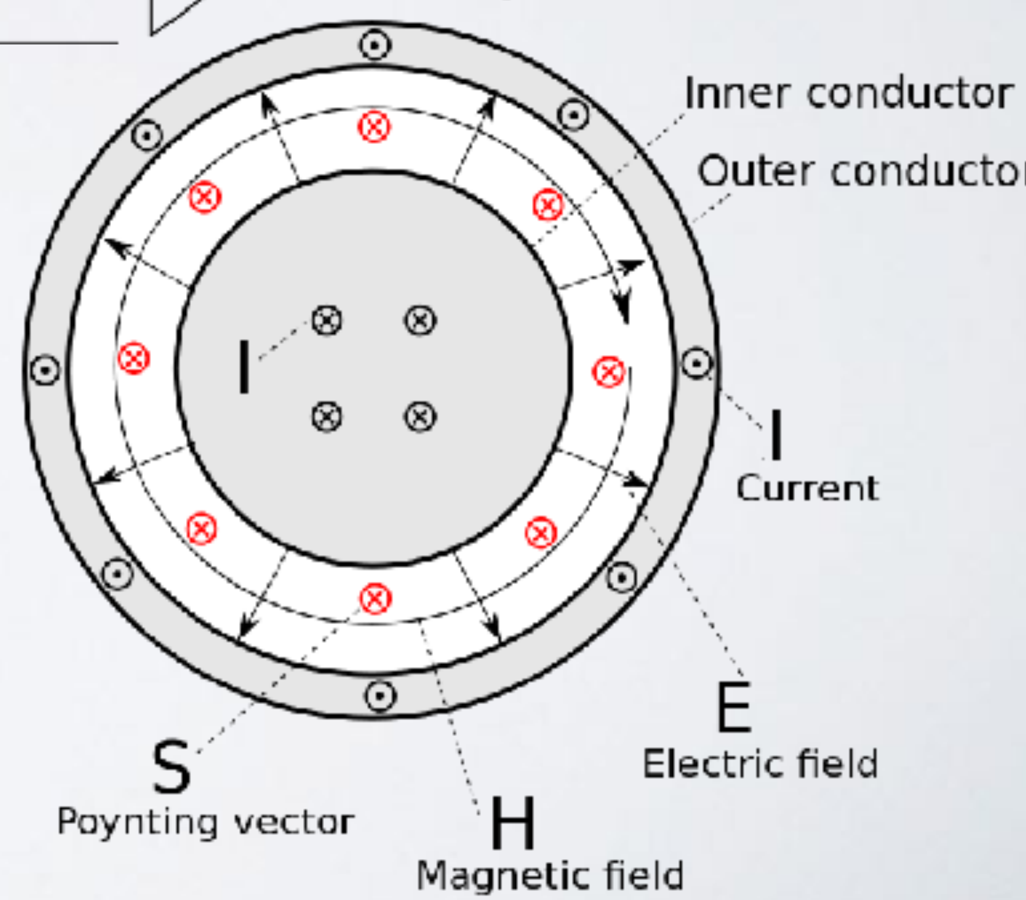

POYNTING SYNTHESIS

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- Most radiation
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  - follows from Z_0 of space
- Effects how we think about
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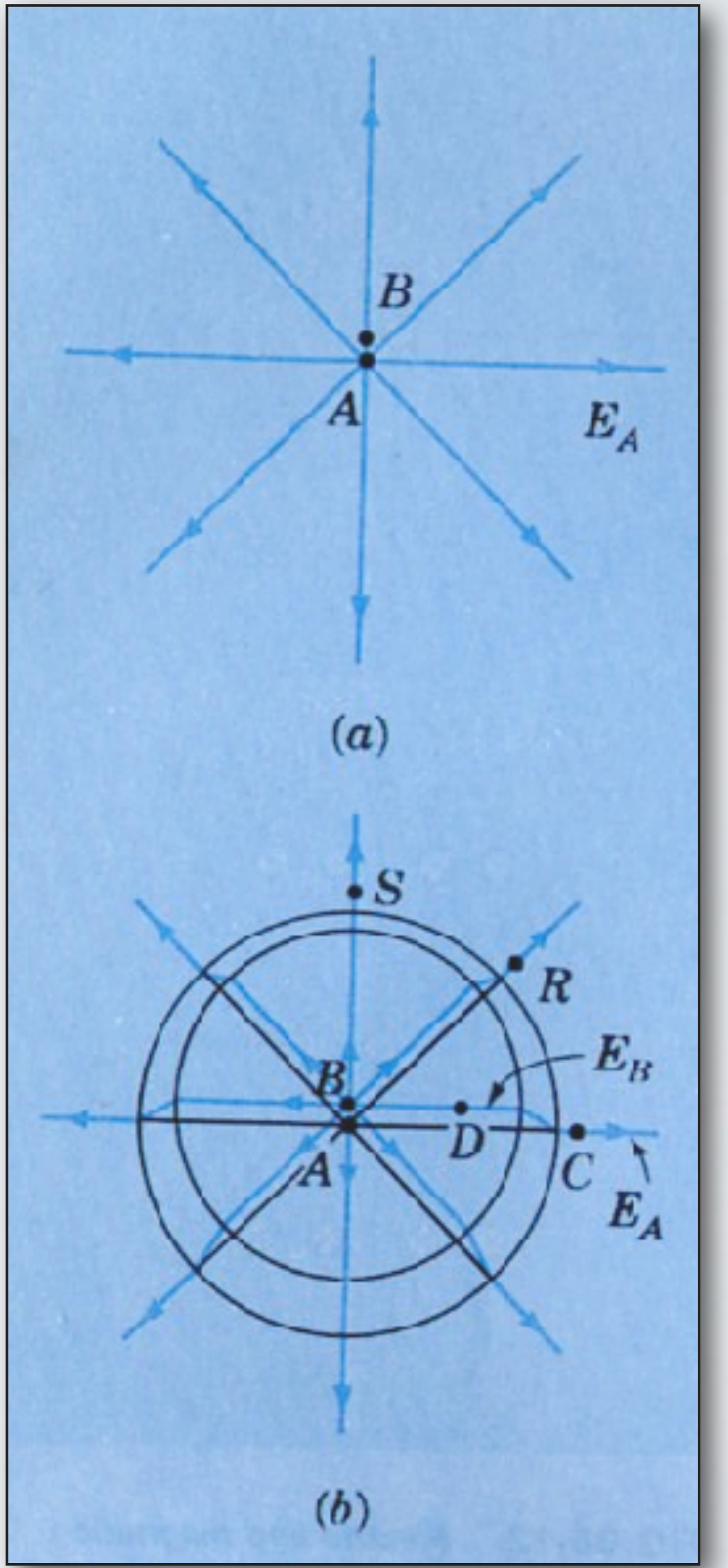

(a)
(b)

PATTERN

- Isotropic
  - no preferred direction - dBi
- All antennas anisotropic
- Given a power ratio
  - 3D surface emerges
- We call that a pattern

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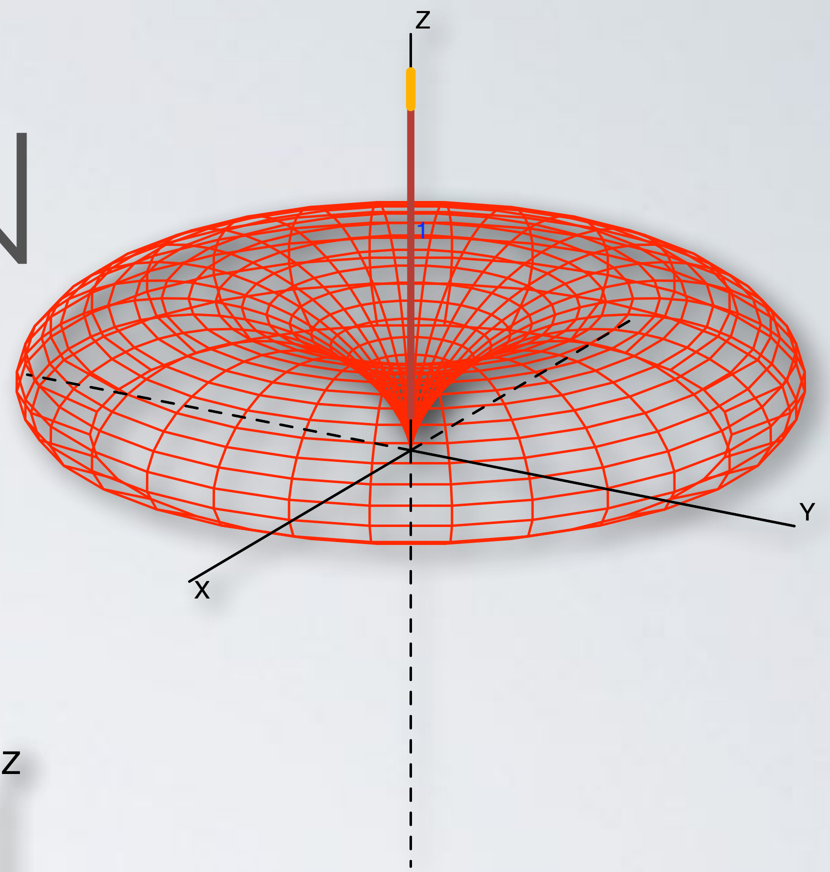

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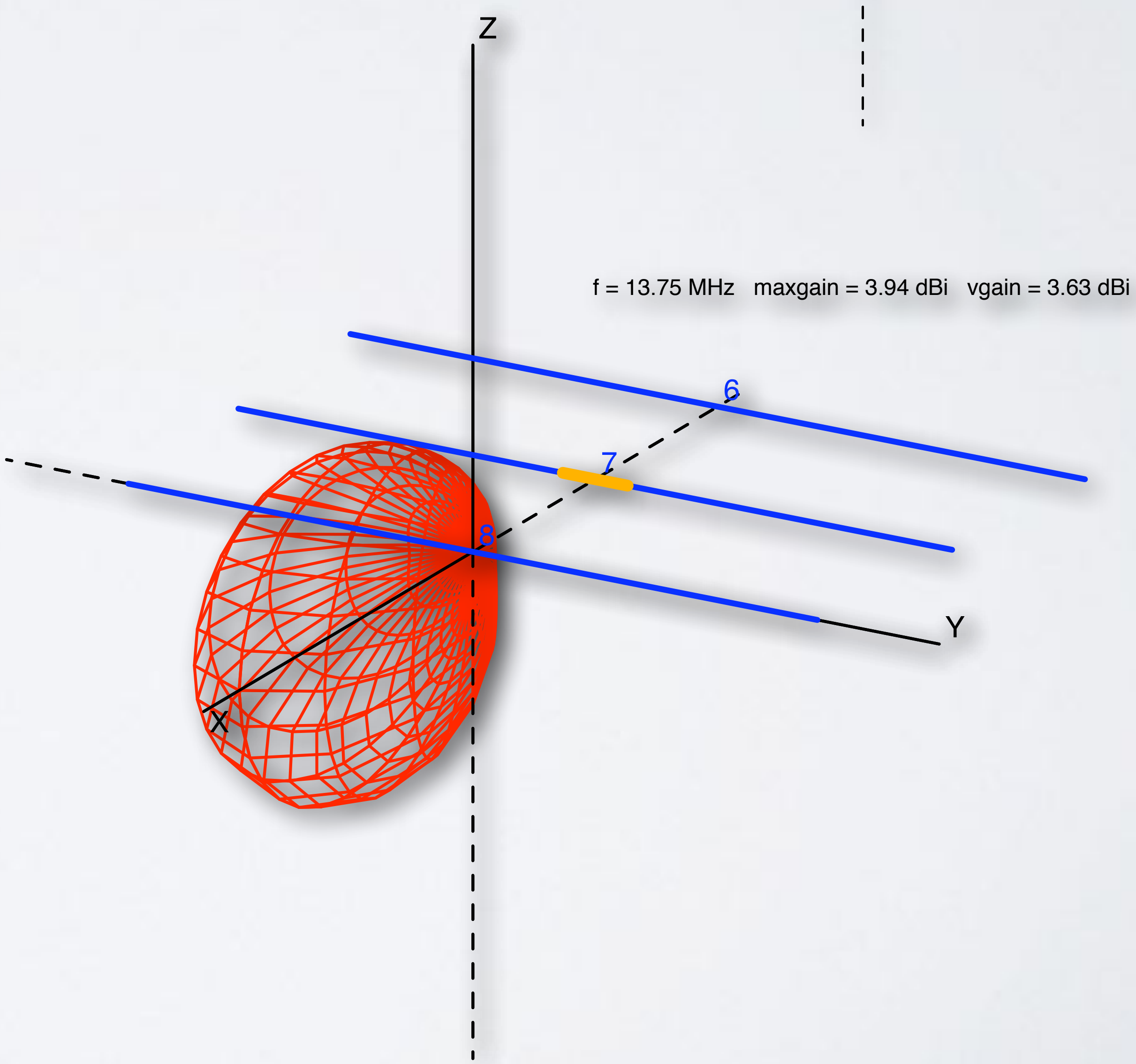

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    - slice horizontally
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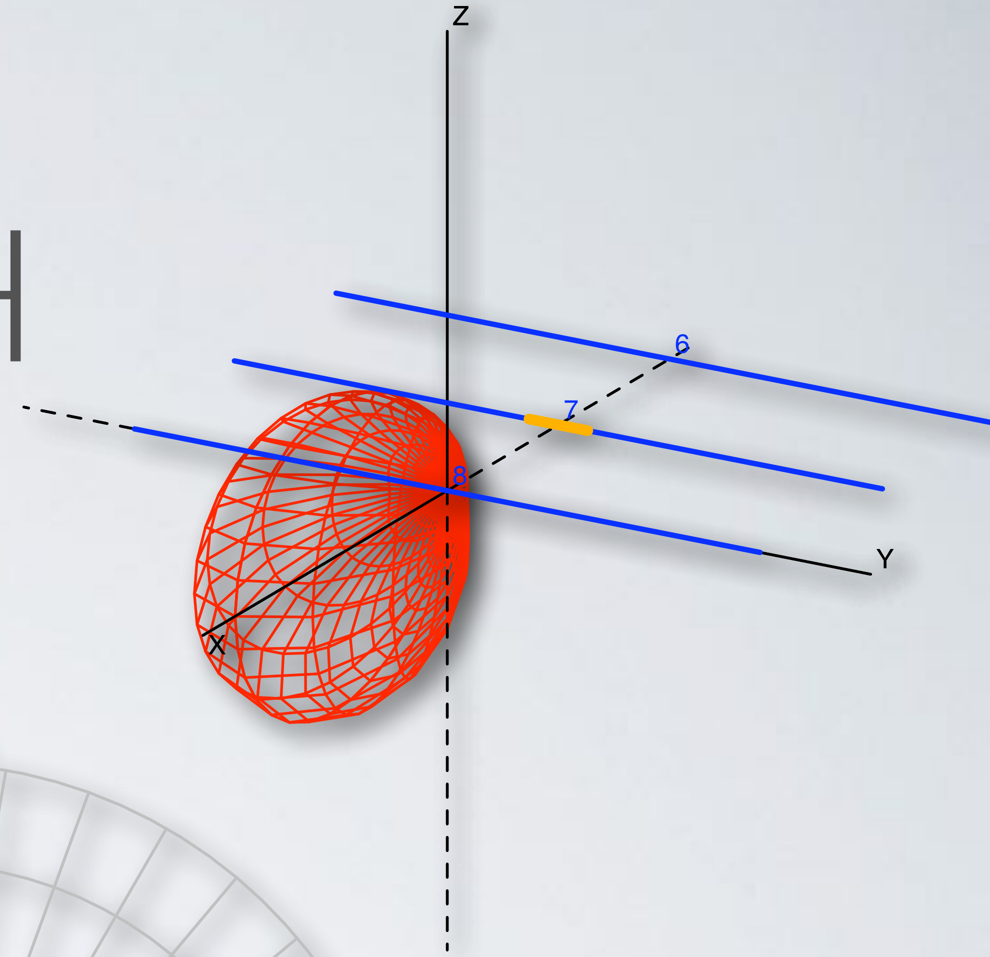
    - directionality

AZIMUTH



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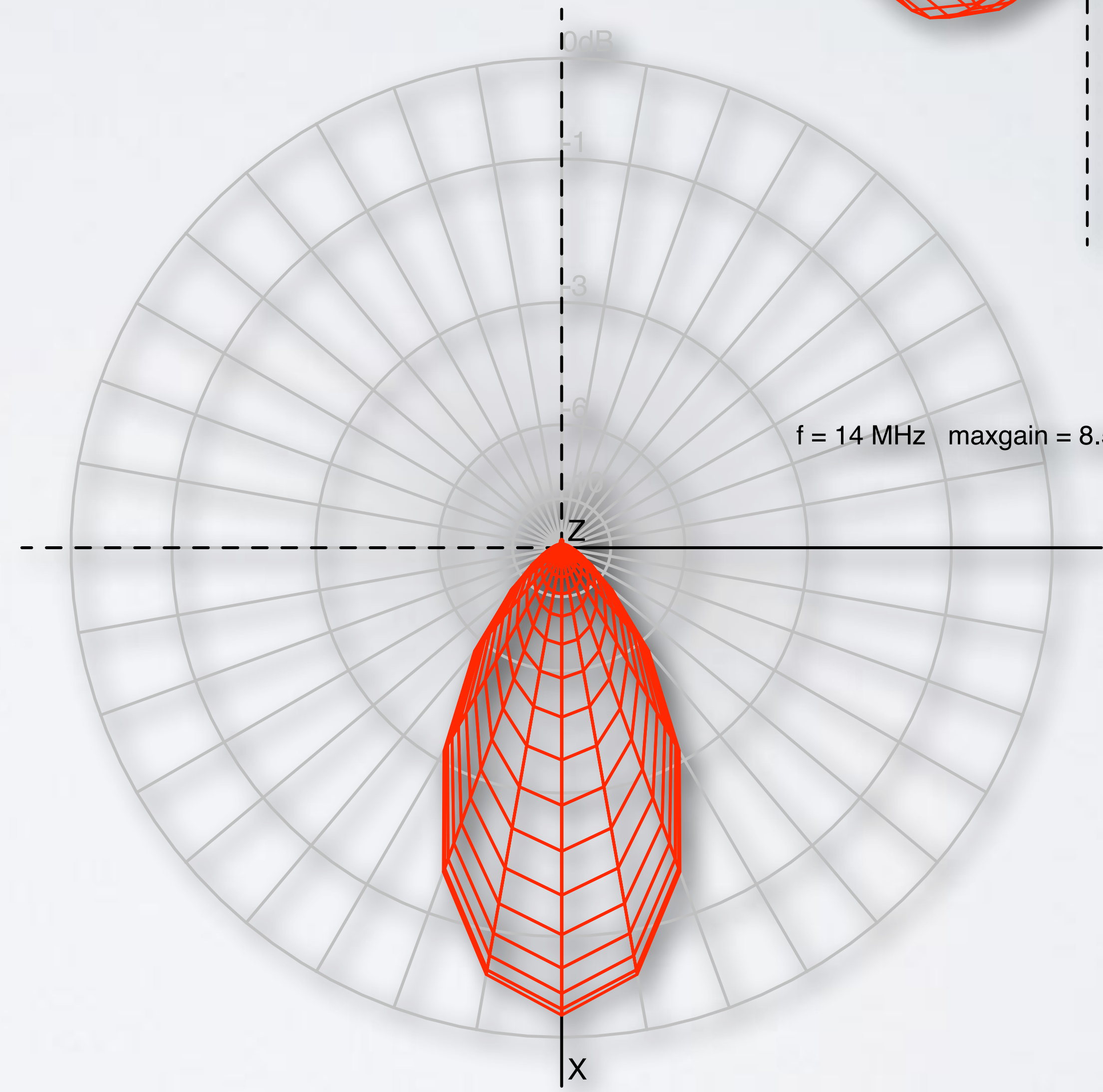
f = 14 MHz maxgain = 8.5 dBi vgain = 5.21 dBi



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ELEVATION

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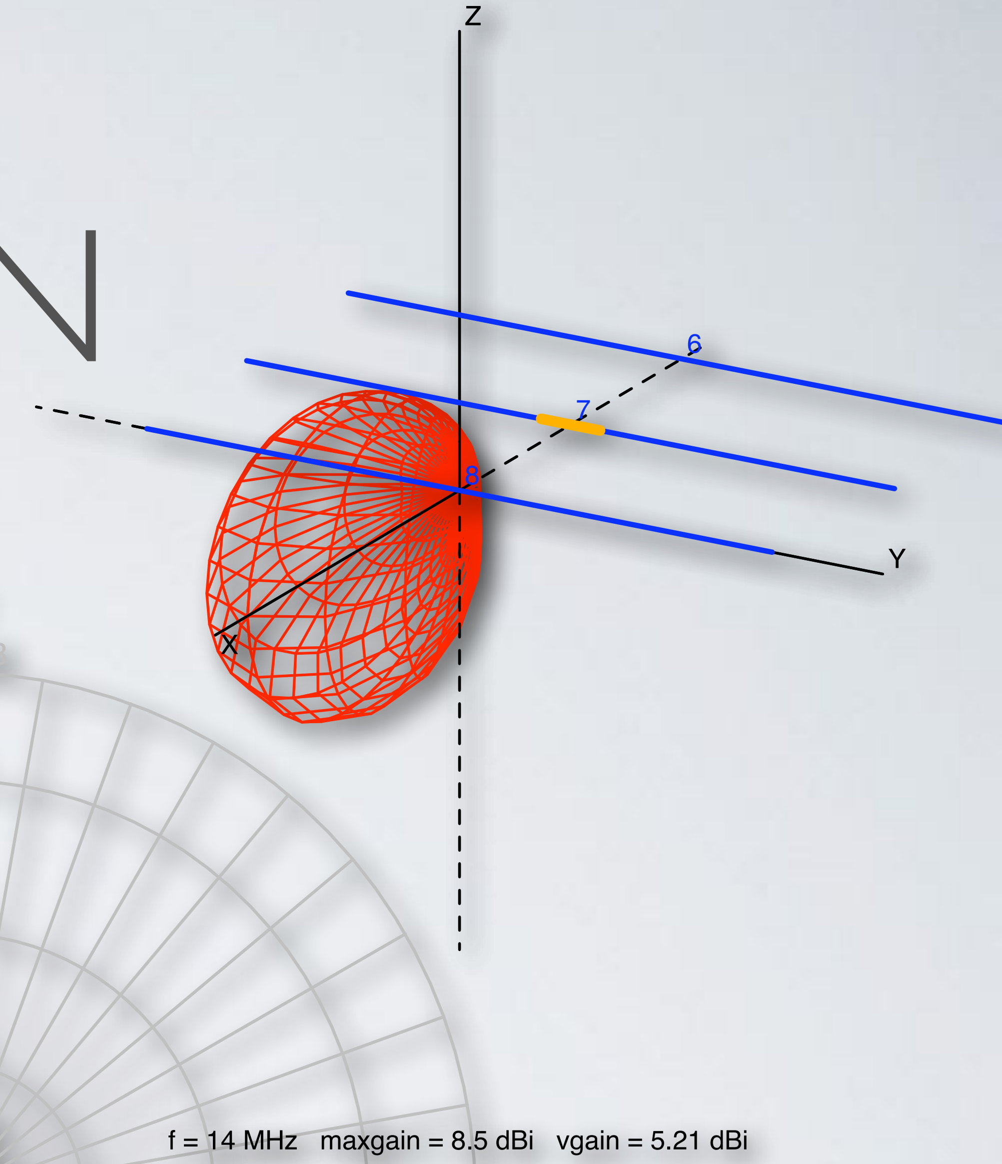

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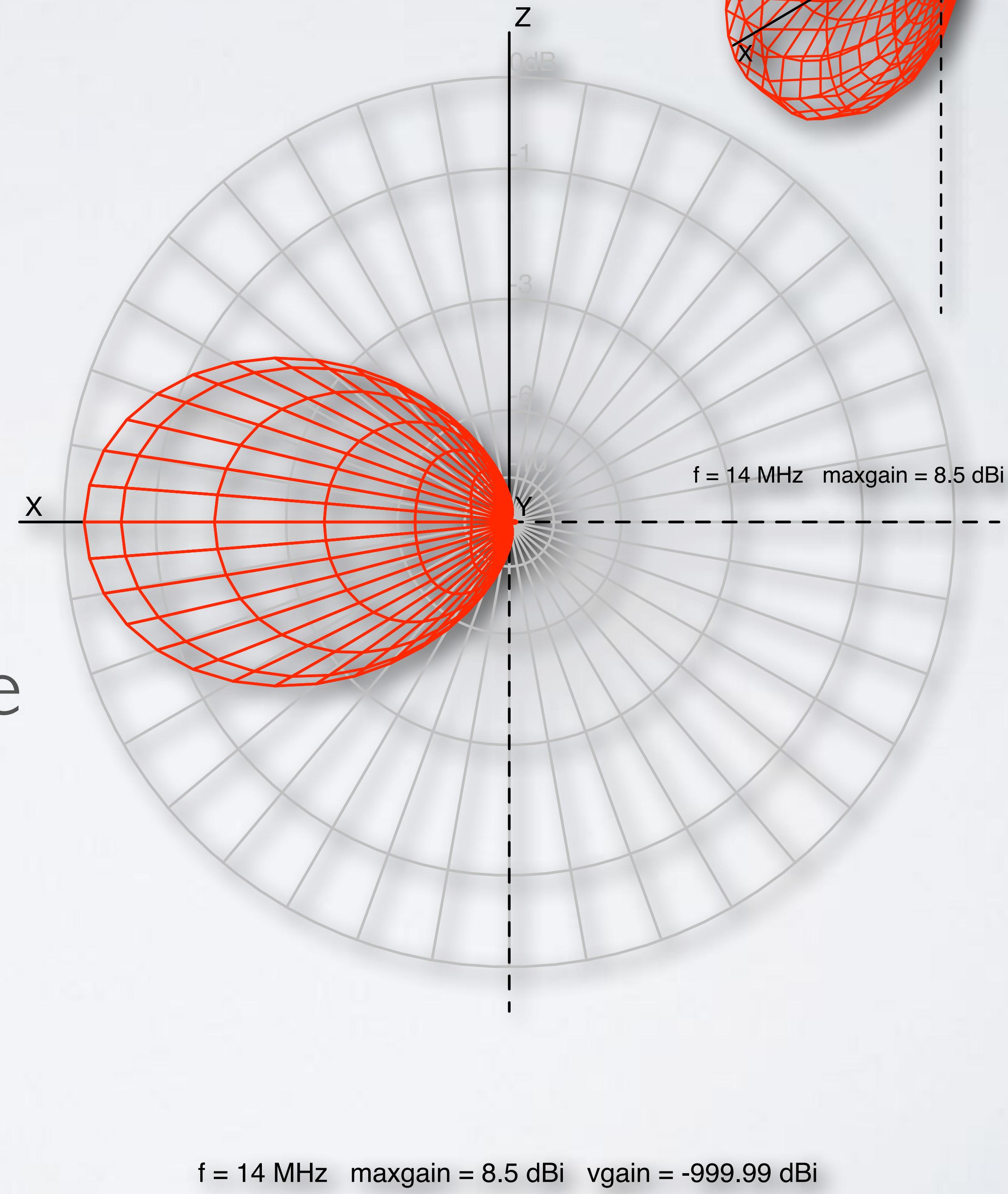

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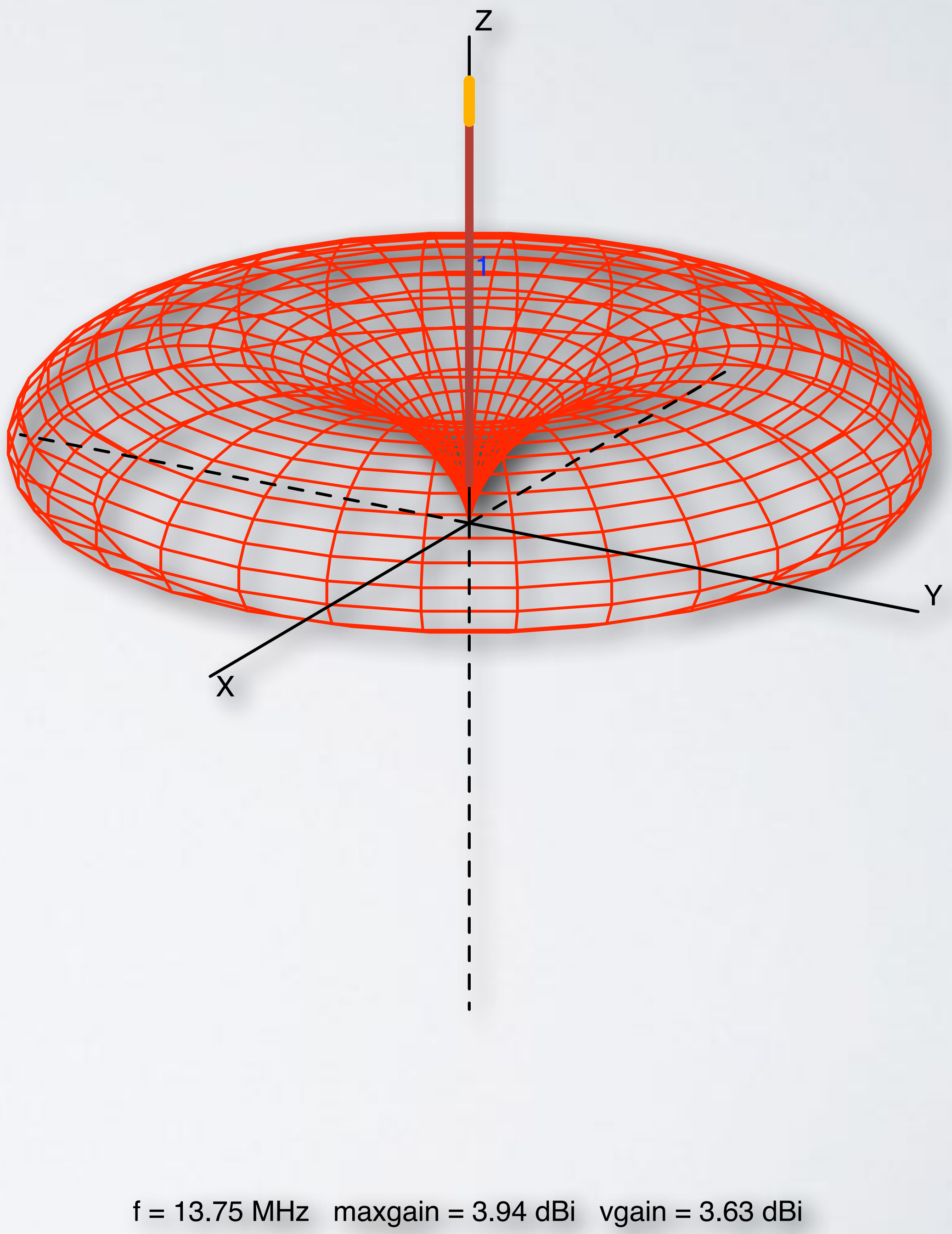

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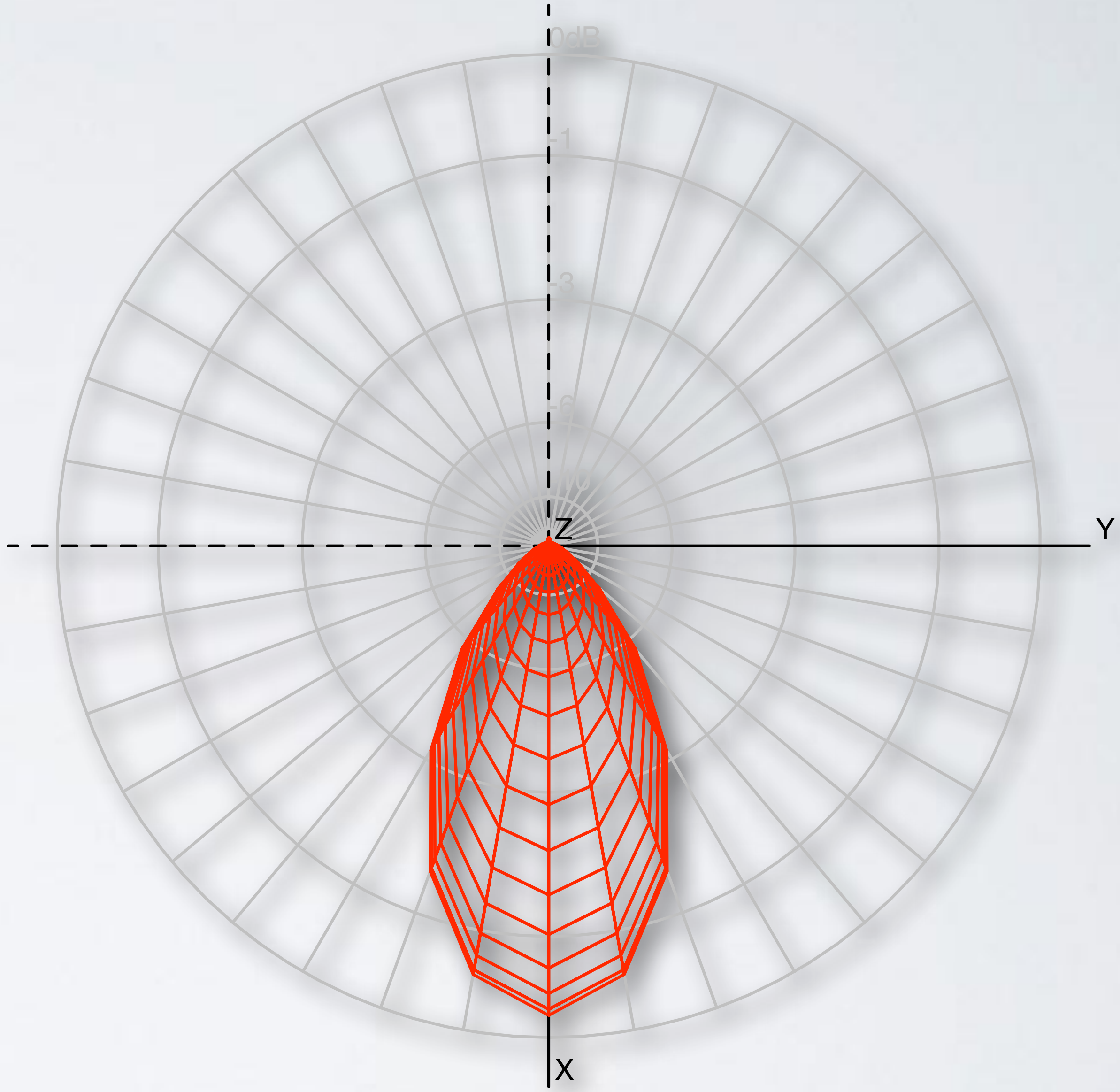

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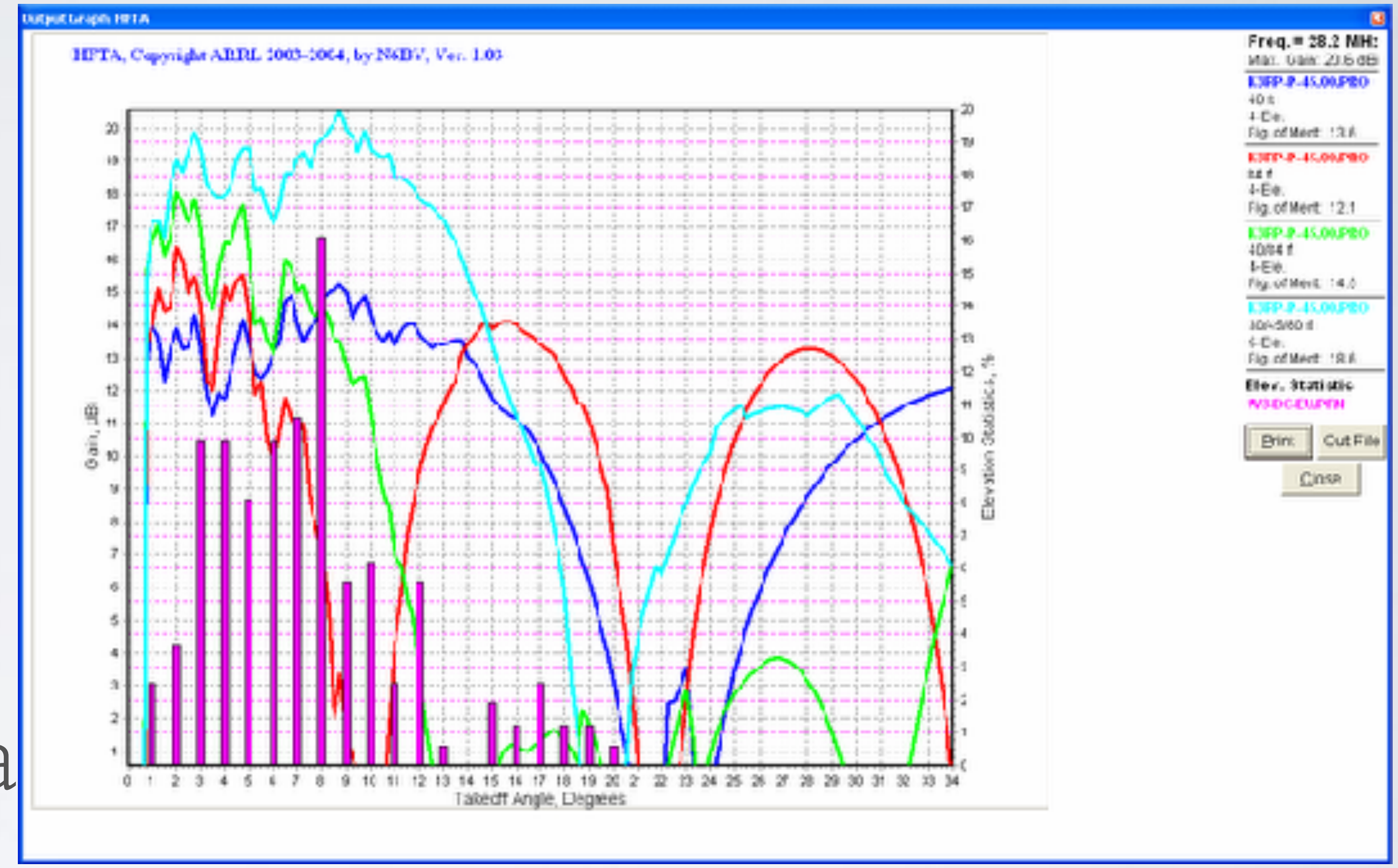

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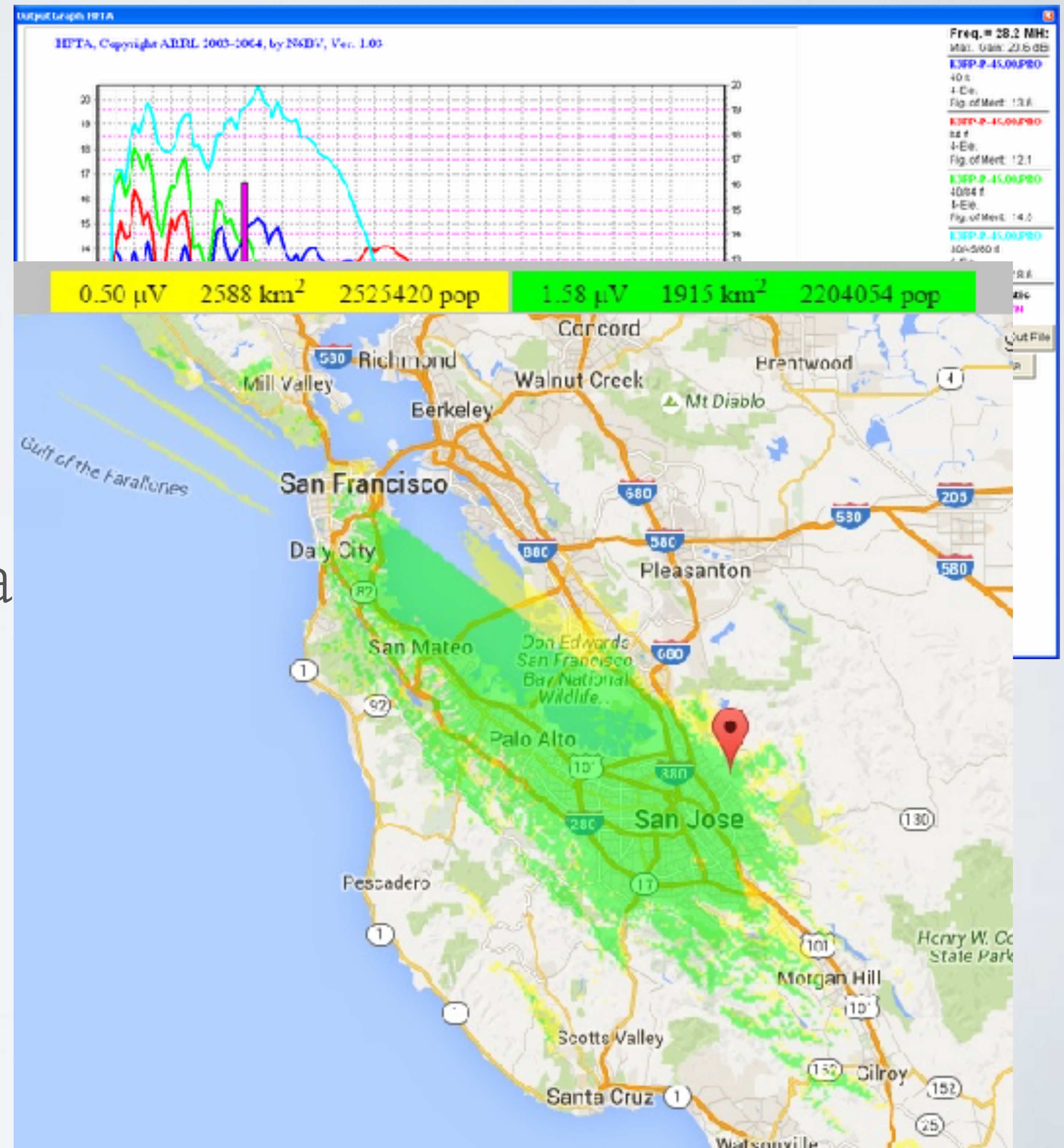

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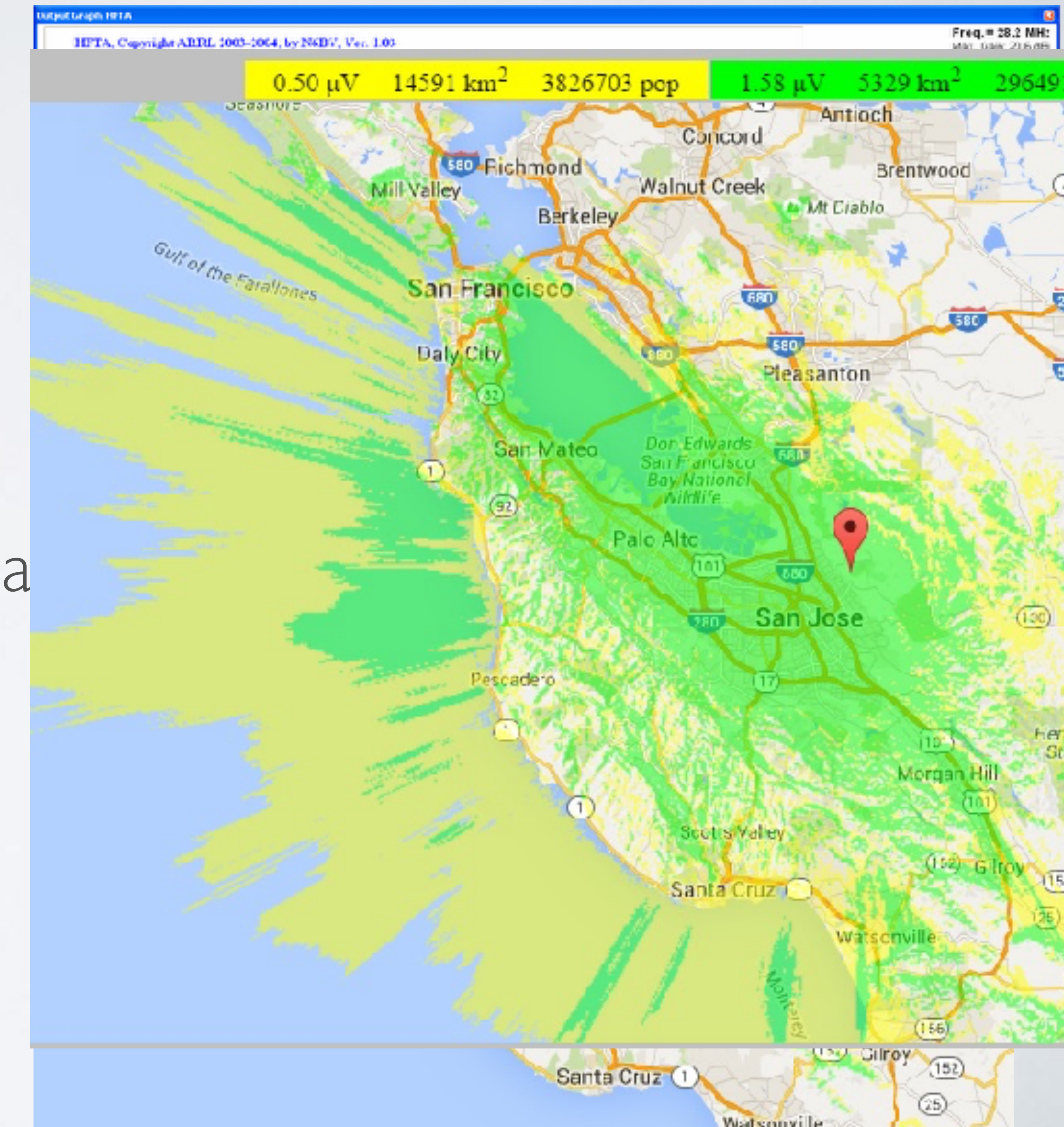

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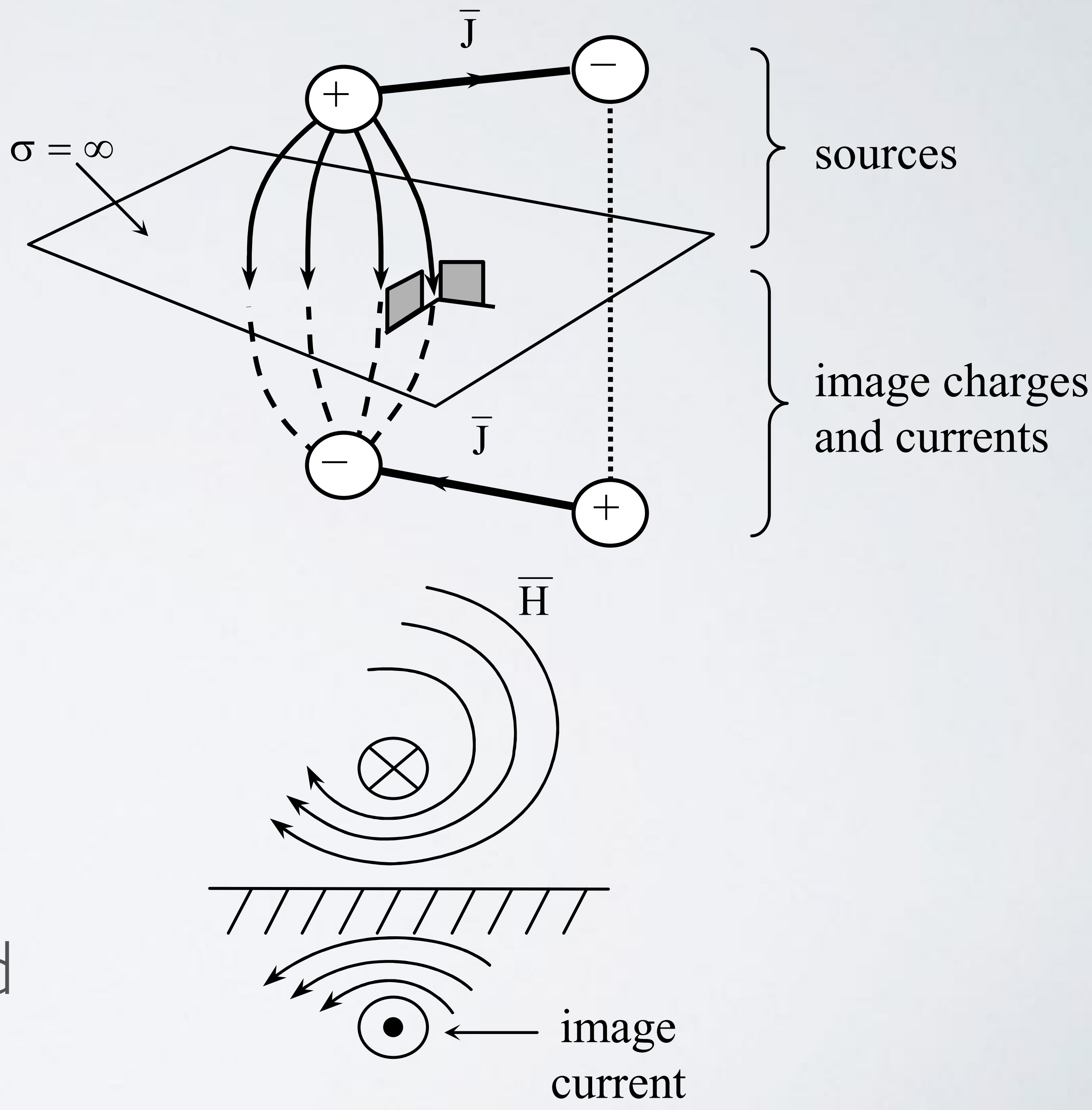

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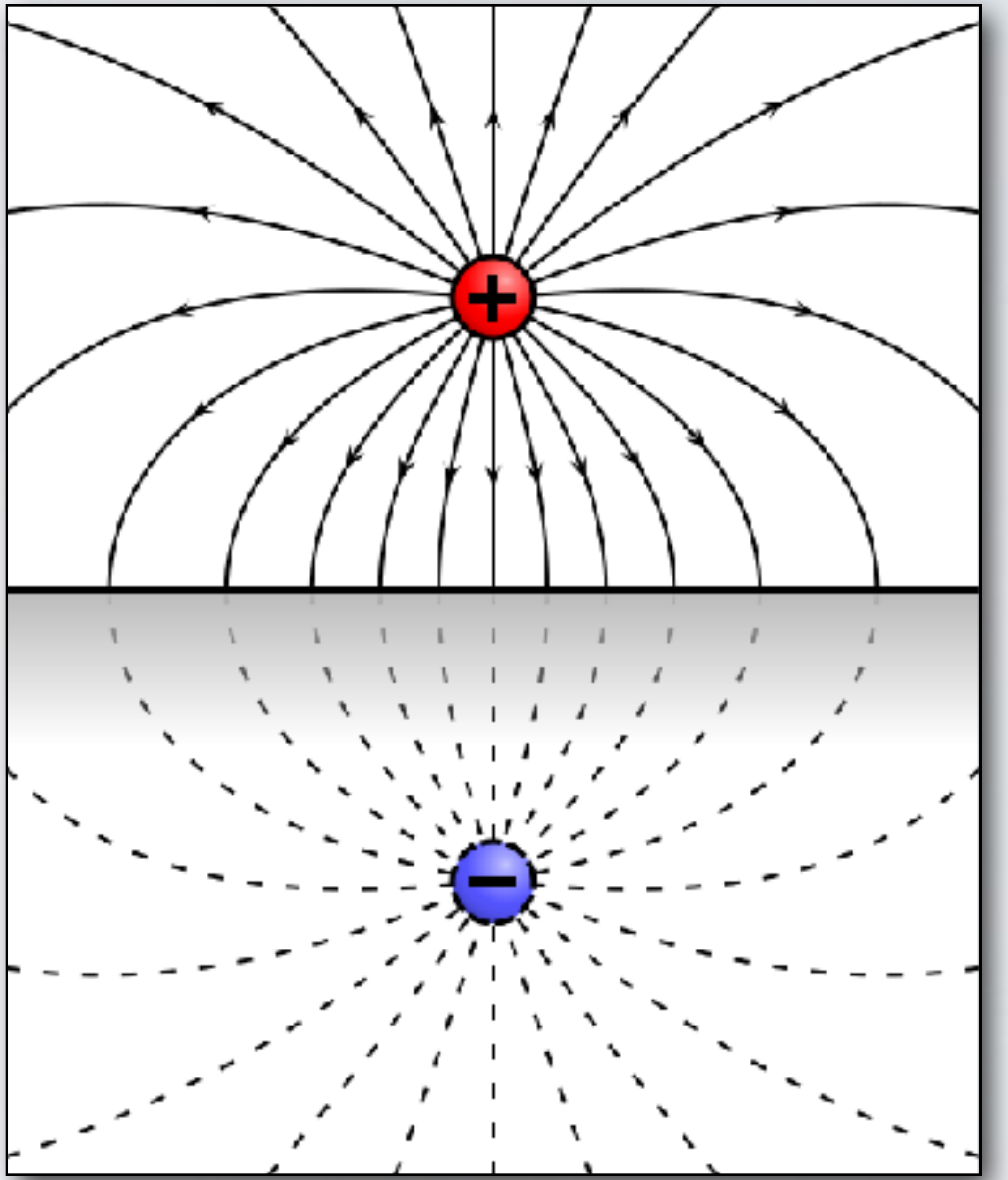

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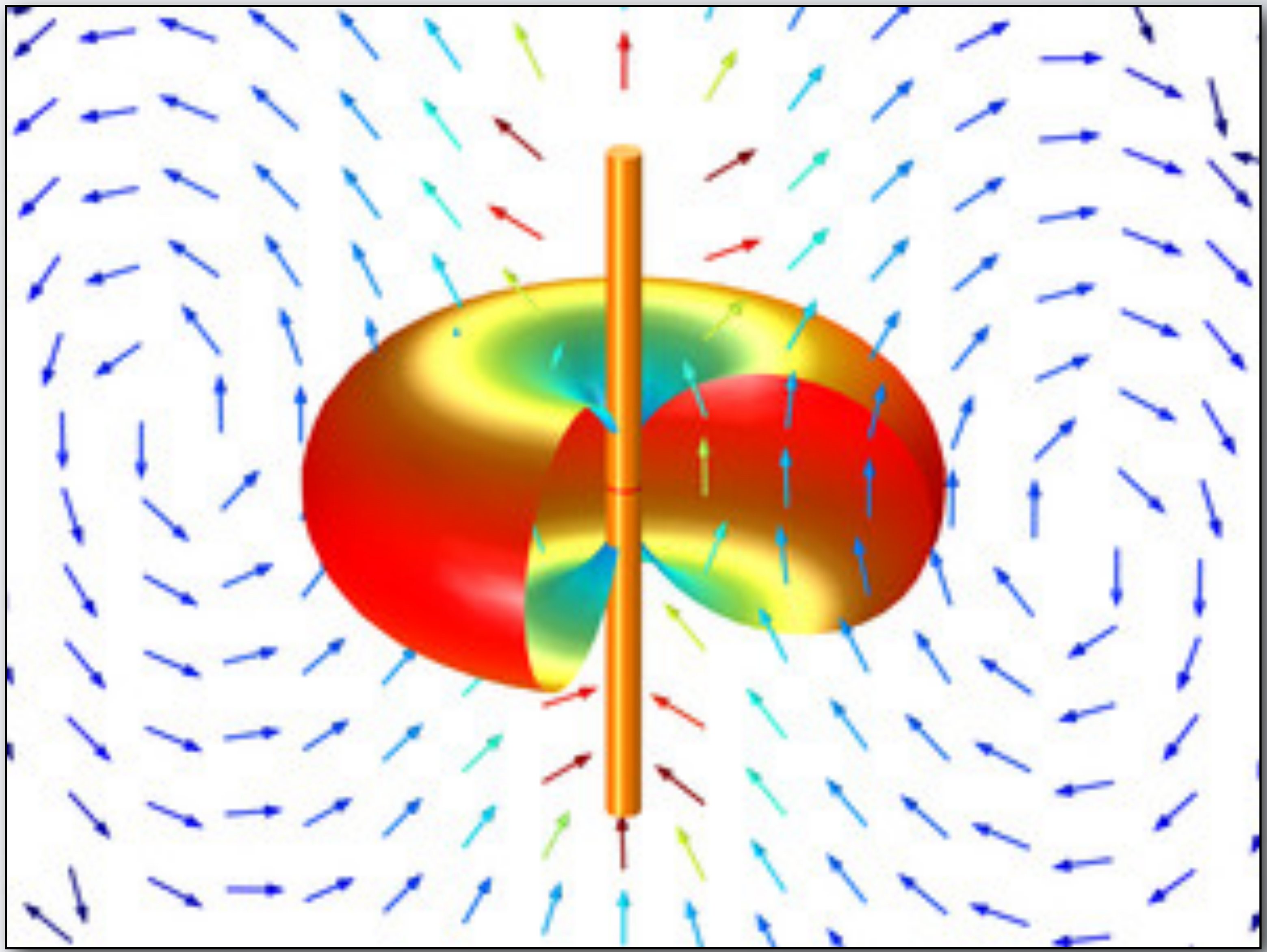

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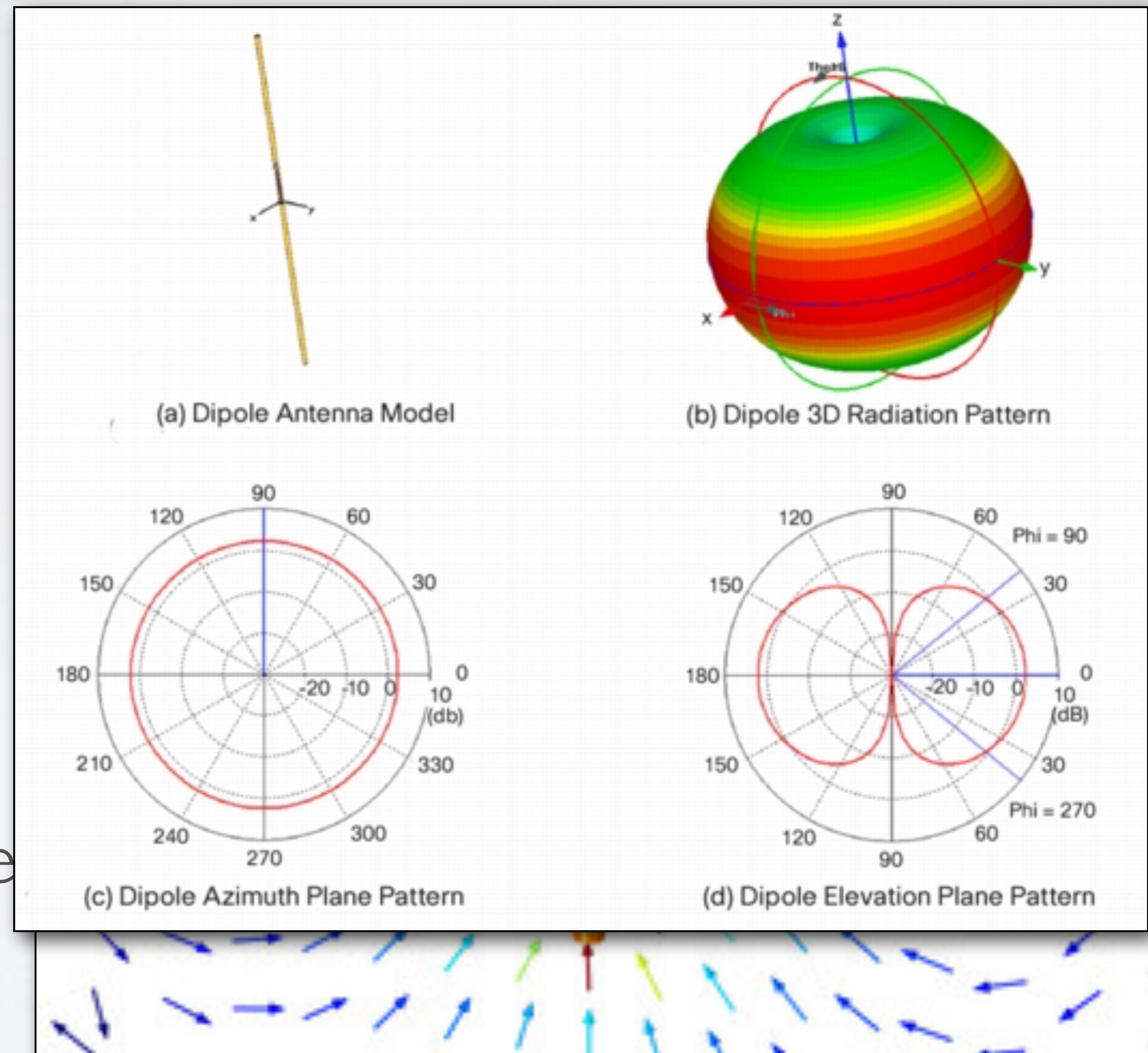

(a) Dipole Antenna Model

(b) Dipole 3D Radiation Pattern

(c) Dipole Azimuth Plane Pattern

(d) Dipole Elevation Plane Pattern

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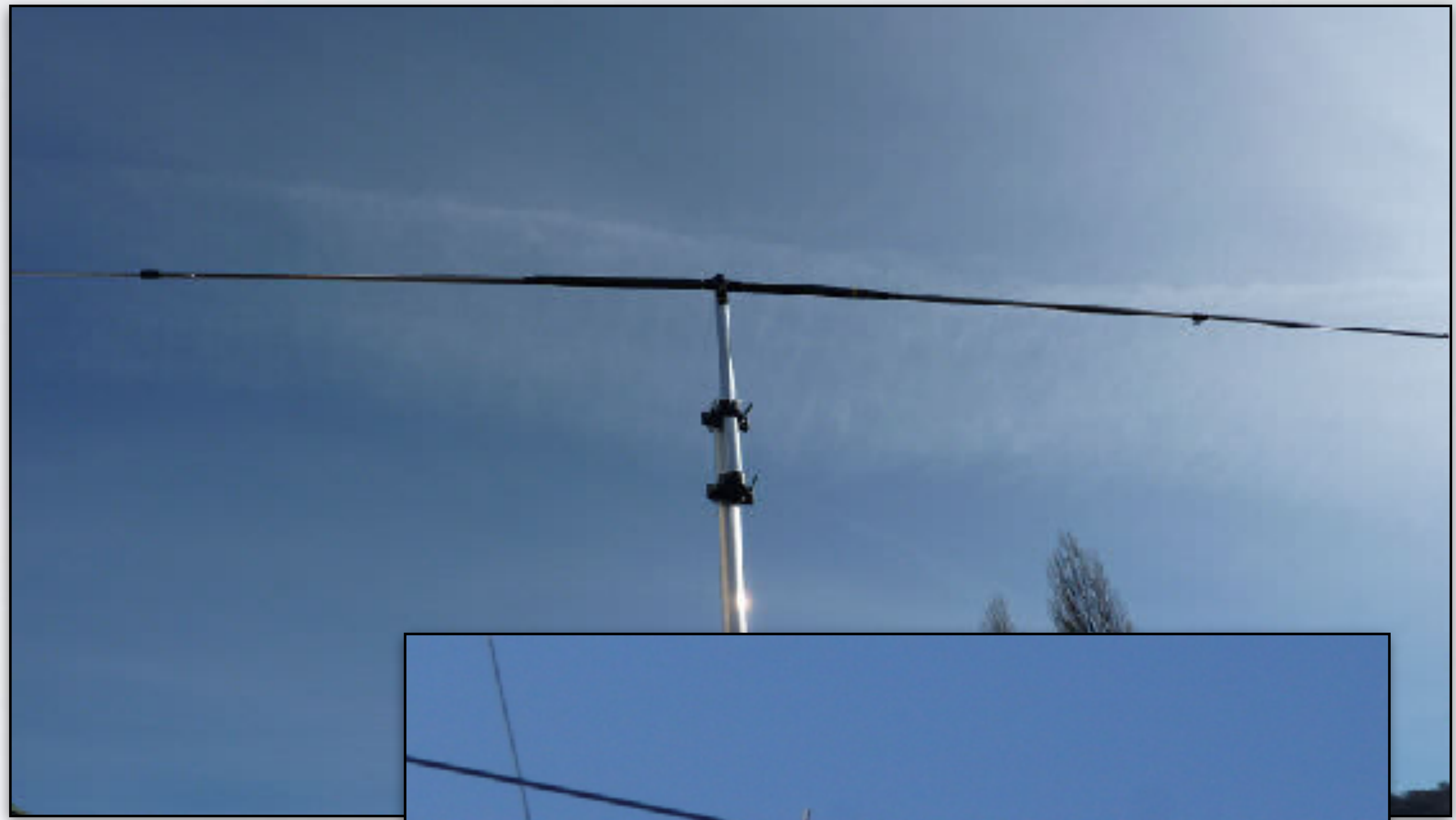

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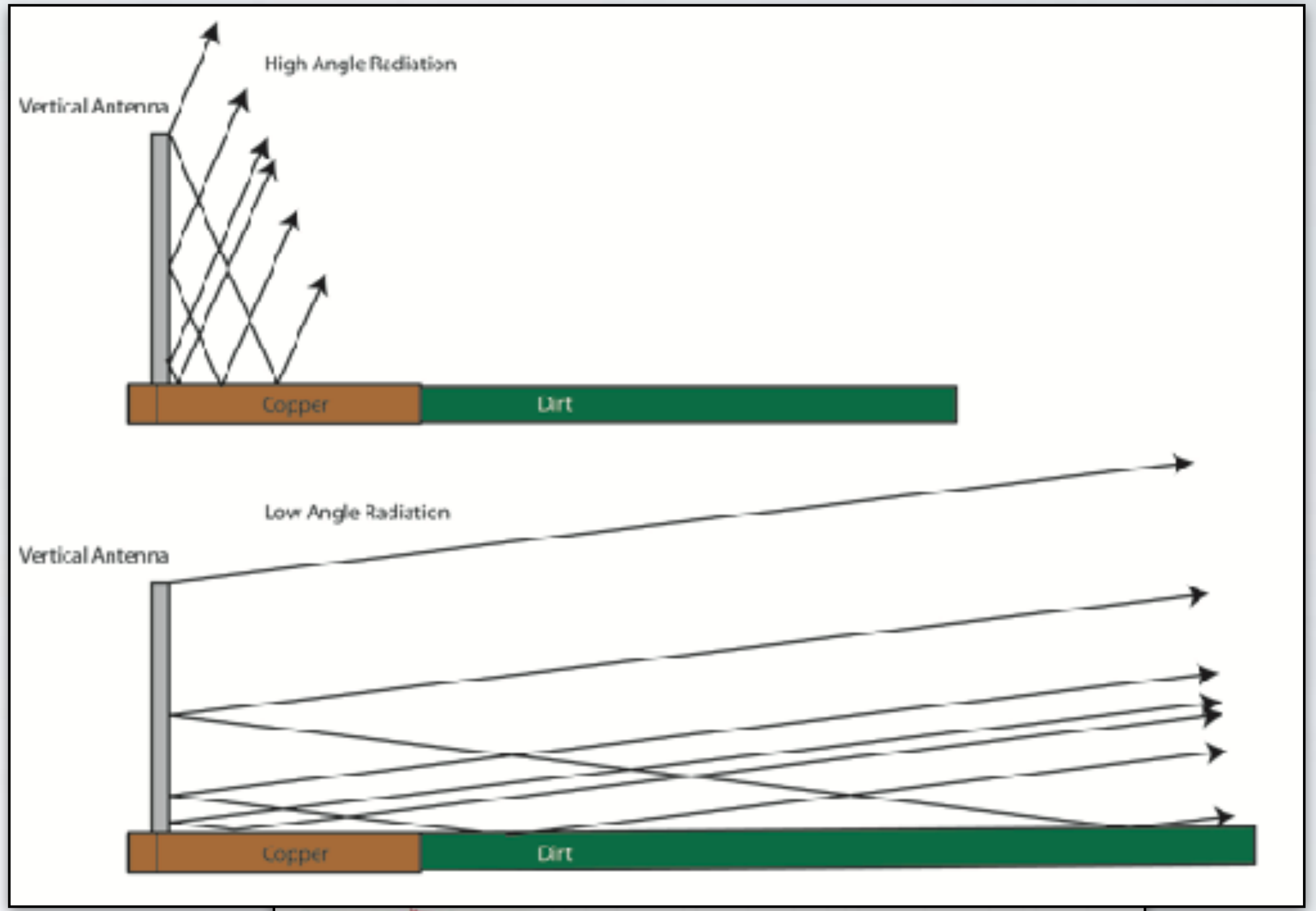

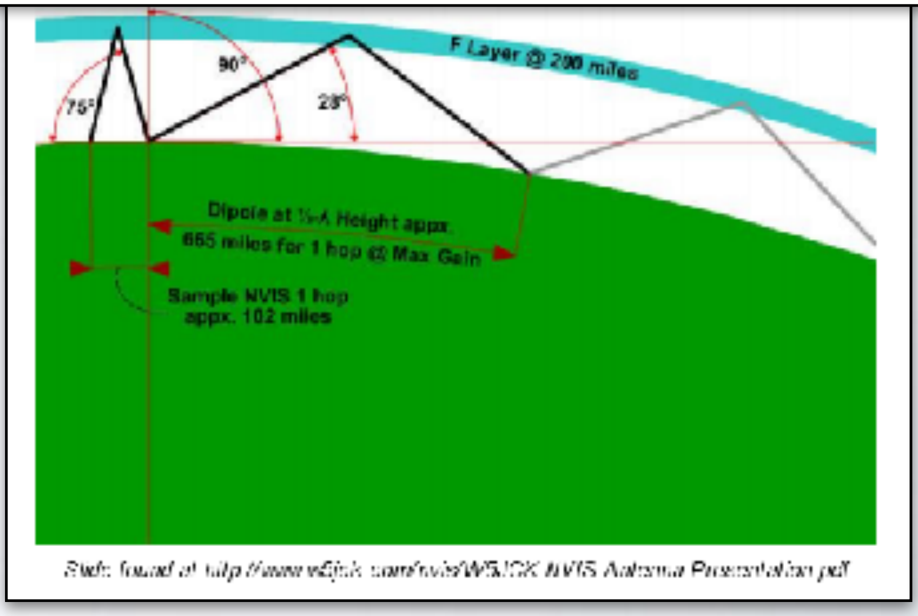

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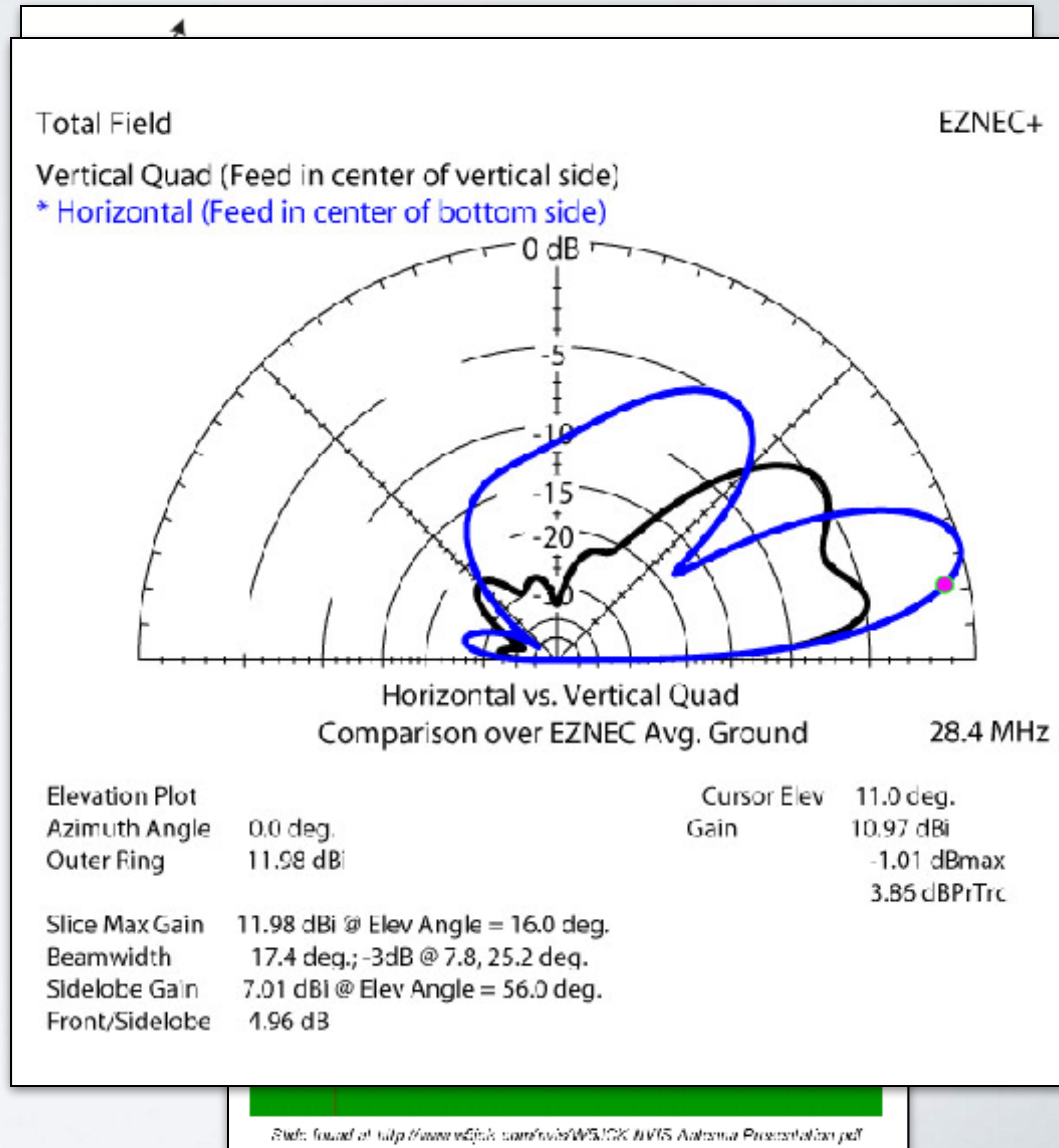

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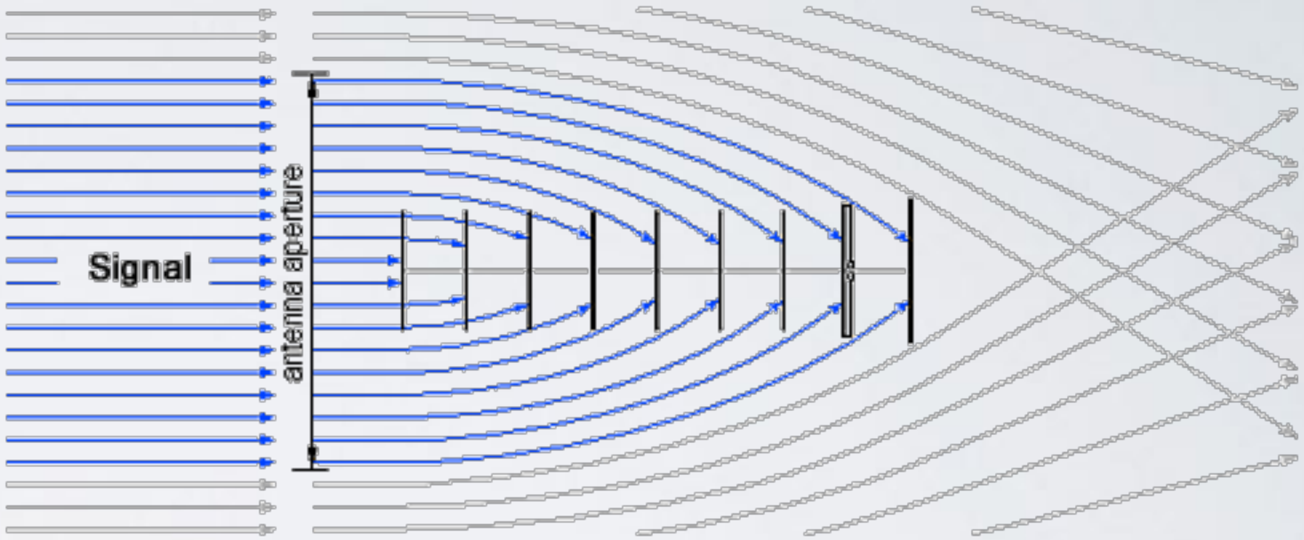

$$A_{eff} = \frac{\lambda^2}{4\pi}$$

$$G = \frac{4\pi A_{phy} e_a}{\lambda^2}$$

$$\frac{P_r}{P_t} = \frac{A_r A_t}{d^2 \lambda^2}$$

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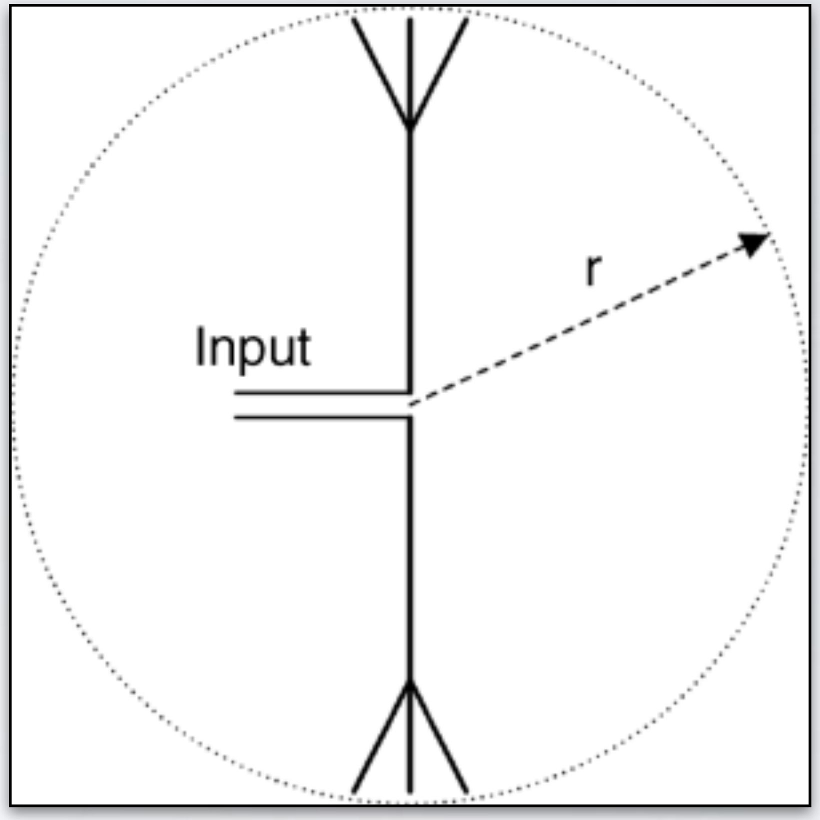

$$Q \geq \frac{1}{k^3 r^3} + \frac{1}{kr}, \quad k = \frac{2\pi}{\lambda}$$

LOSS

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- Heating some wire
- Heating a coil
- Heating the feed line

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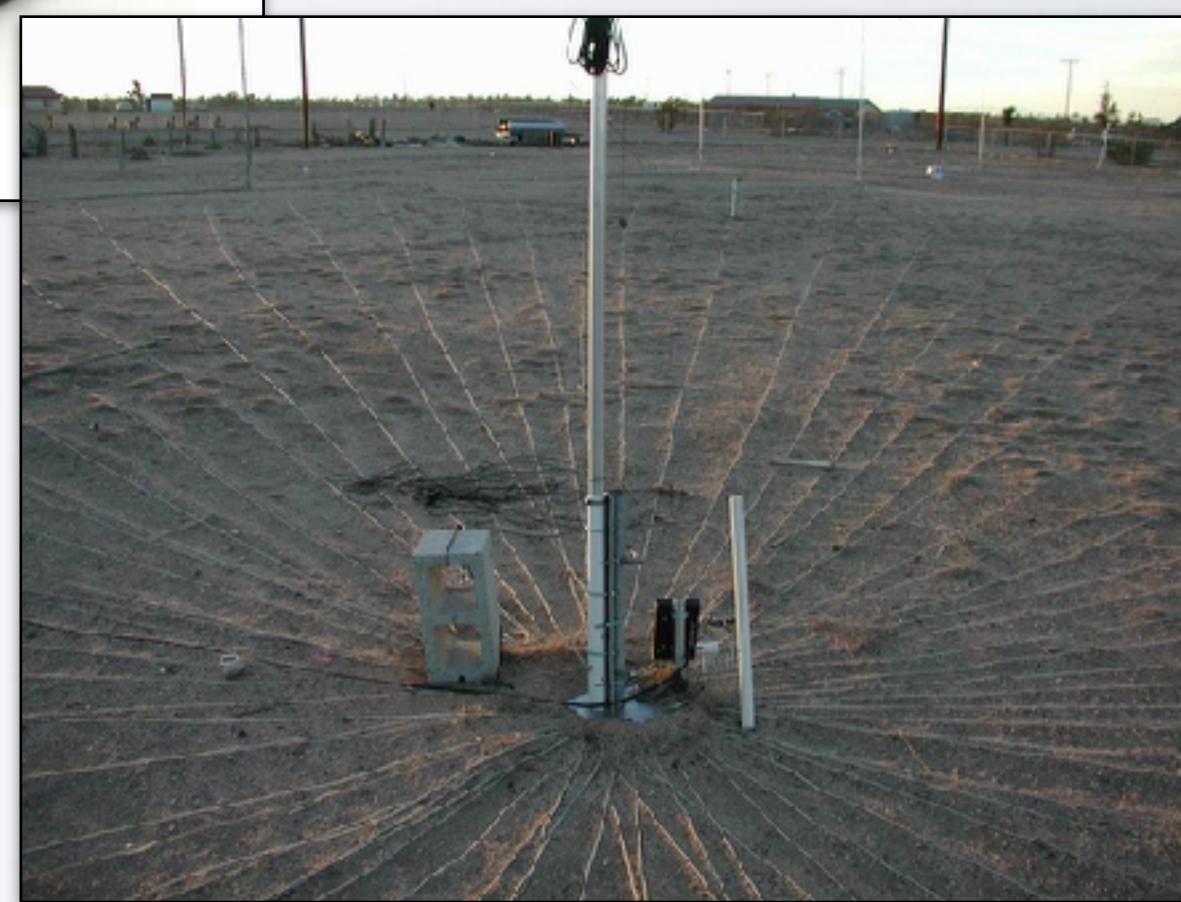

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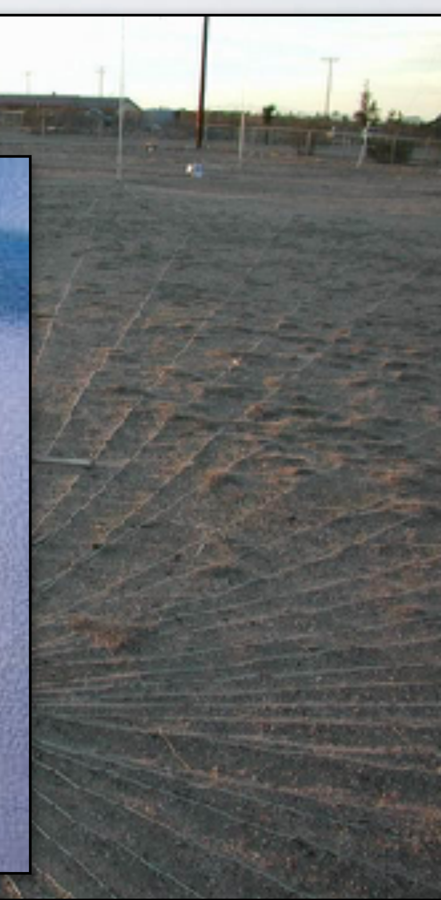

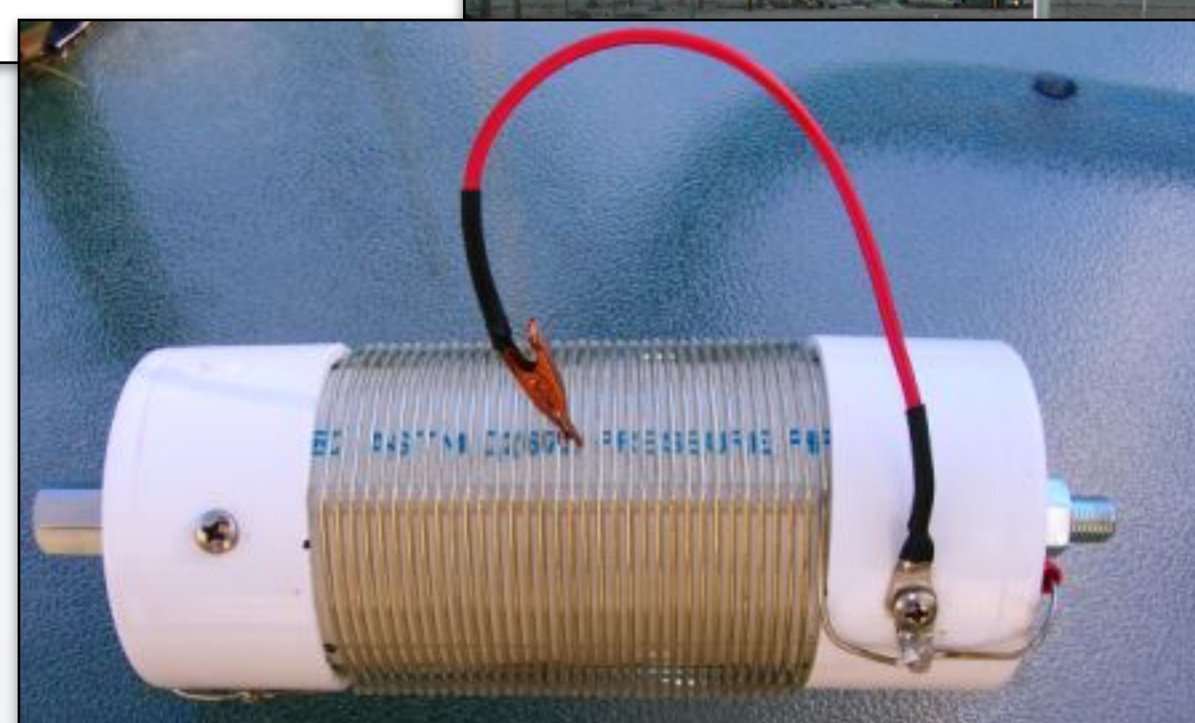

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- Increase radiation resistance
  - lower loss resistance
- Choose aperture / gain
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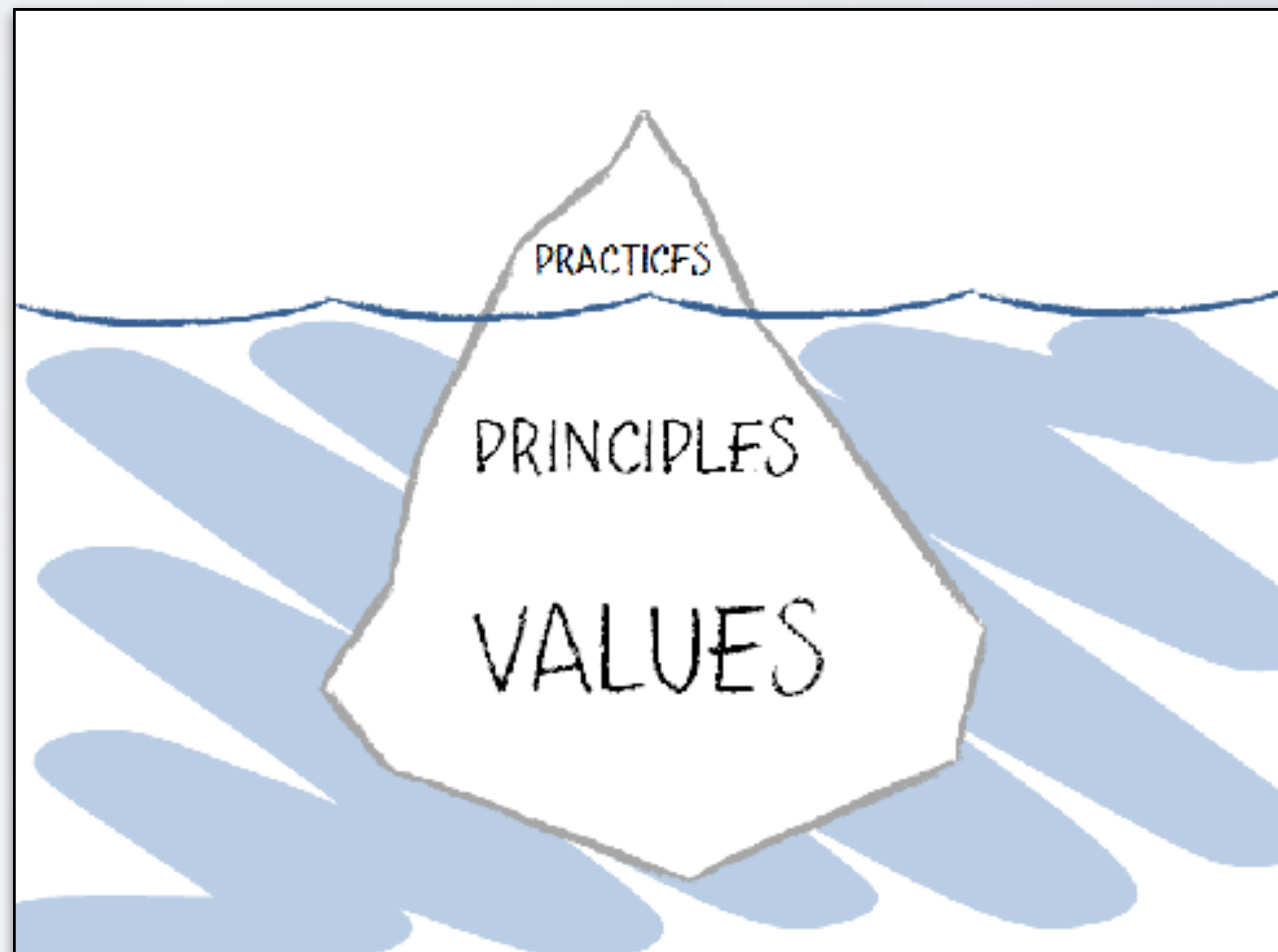

A LENS

- With this, what do we do?
- Look at each antenna
  - how does it stack up?
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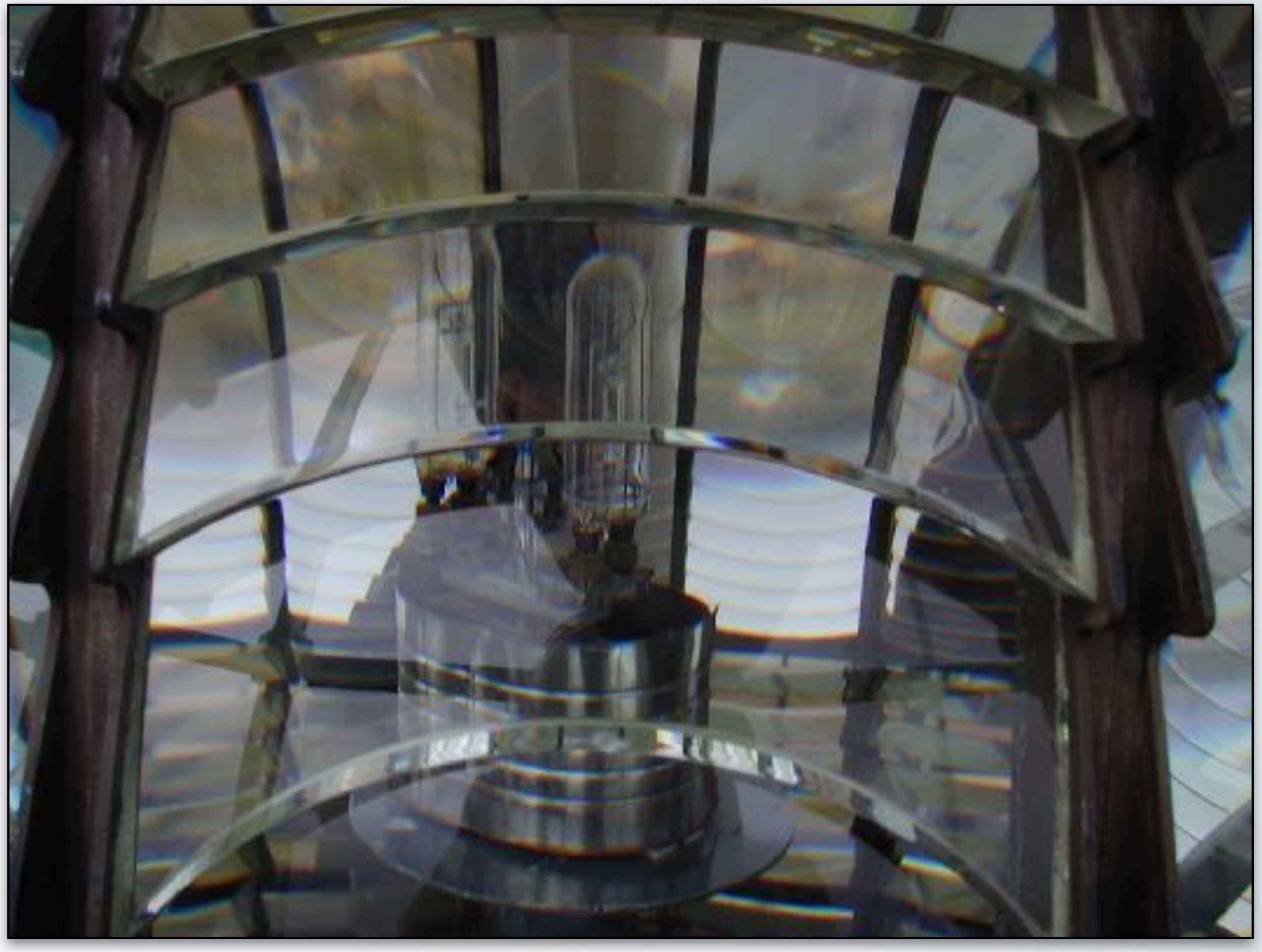

QUICK NOTE ABOUT SWR

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- Not about efficiency (much)
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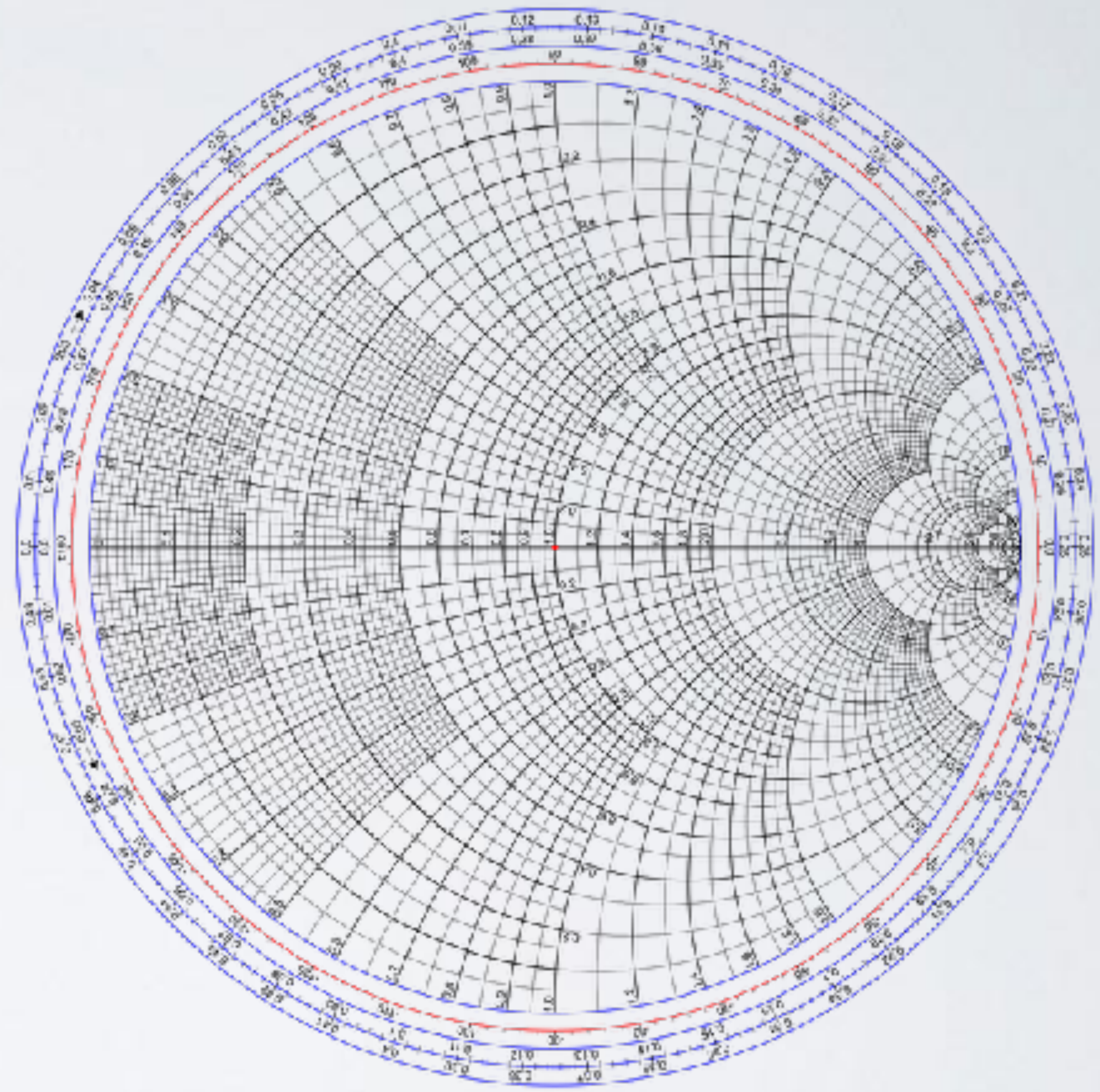

$$\Gamma = \frac{Z - Z_0}{Z + Z_0}, \quad VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|}$$

A FEW EXAMPLES

- Monopole
- Shortened monopole
- Yagi
- G5RV
- Large and Small loop
- End-fed 1/2 wave
- J-pole
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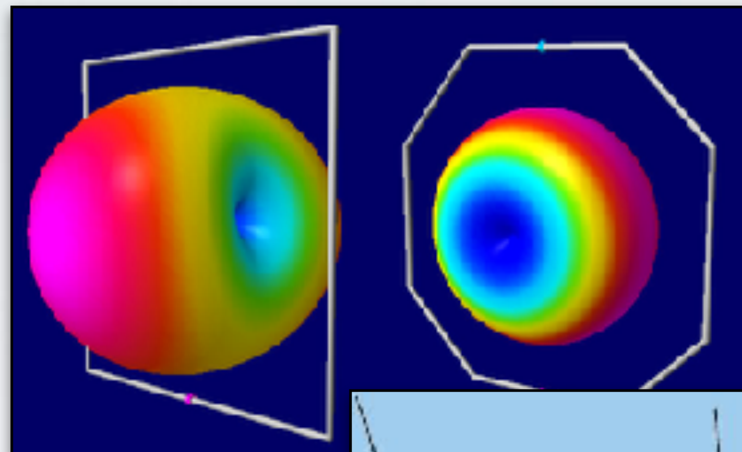
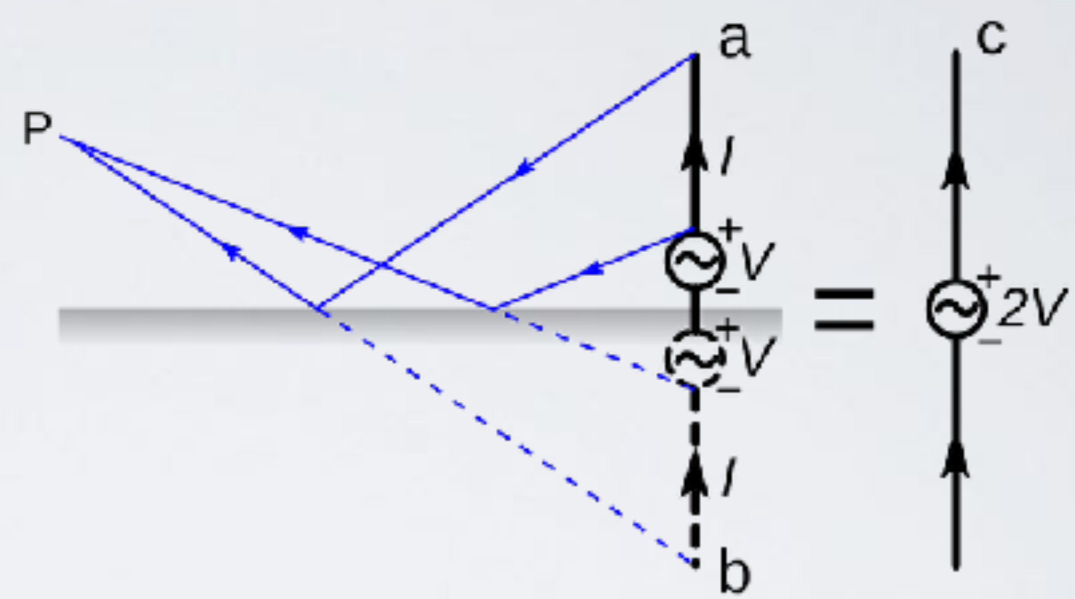


MONOPOLE

- 5 dB gain over isotropic
- Medium R_{rad} 36 ohms
- Height not required
  - long but simple
- Low Q, but watch for loss
- Omnidirectional Az pattern

MONOPOLE



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SHORTENED MONOPOLE OR DIPOLE

- Lower gain, depends
- Lower $R_{rad,}$ depends
- Height not required
  - shorter, but tradeoff
- Medium to high Q
- Pattern concentrated at high current, below coil

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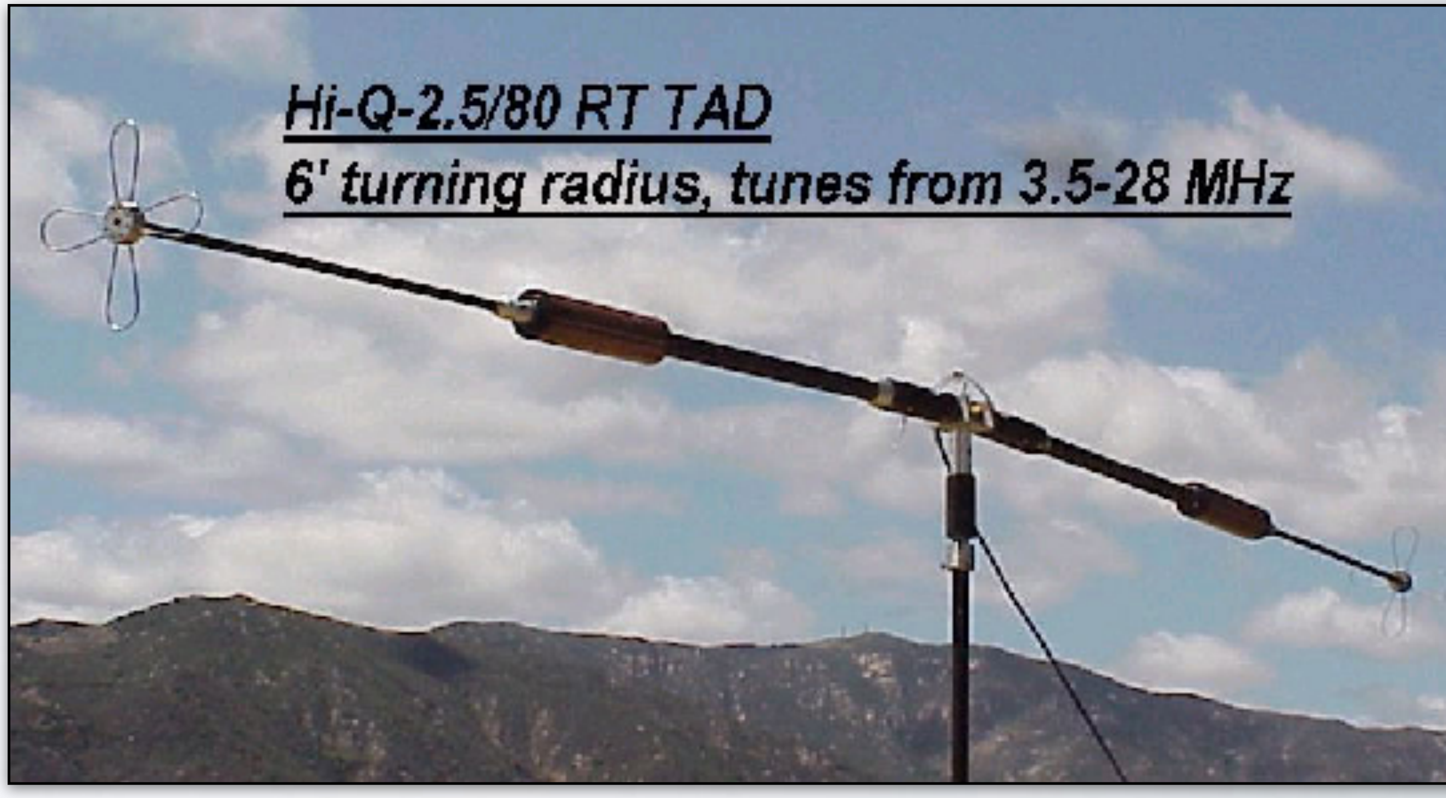
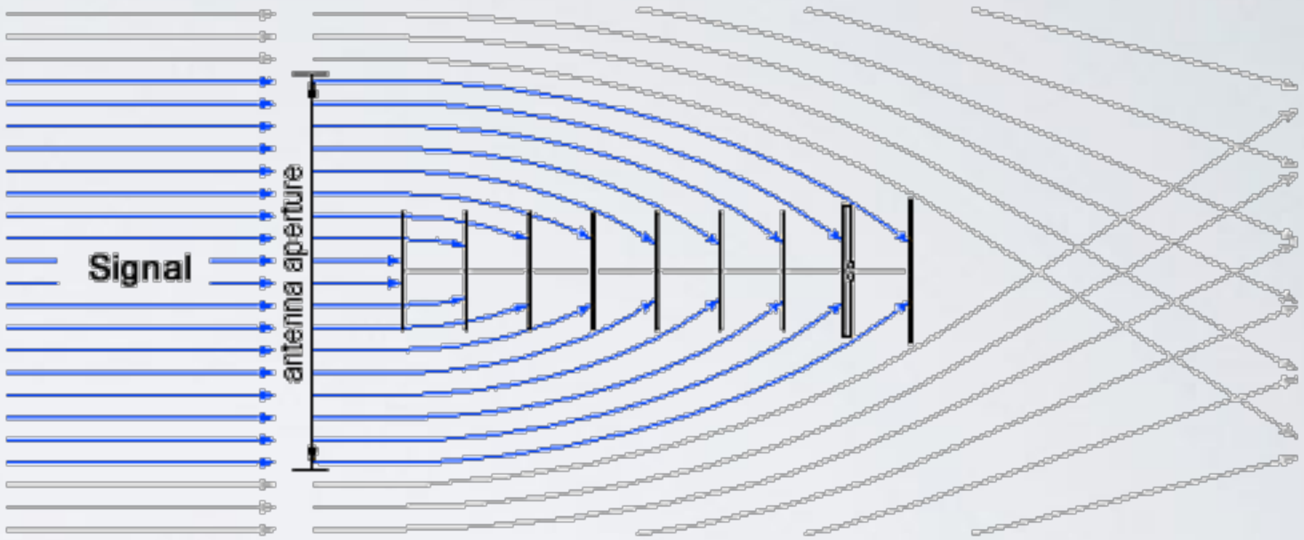


HORIZONTAL YAGI

- High gain, depends on geometry
- Low R_{rad} ?
- Height required for low angle
  - large and heavy
- Medium - high Q
- Directional pattern, high ERP

HORIZONTAL YAGI



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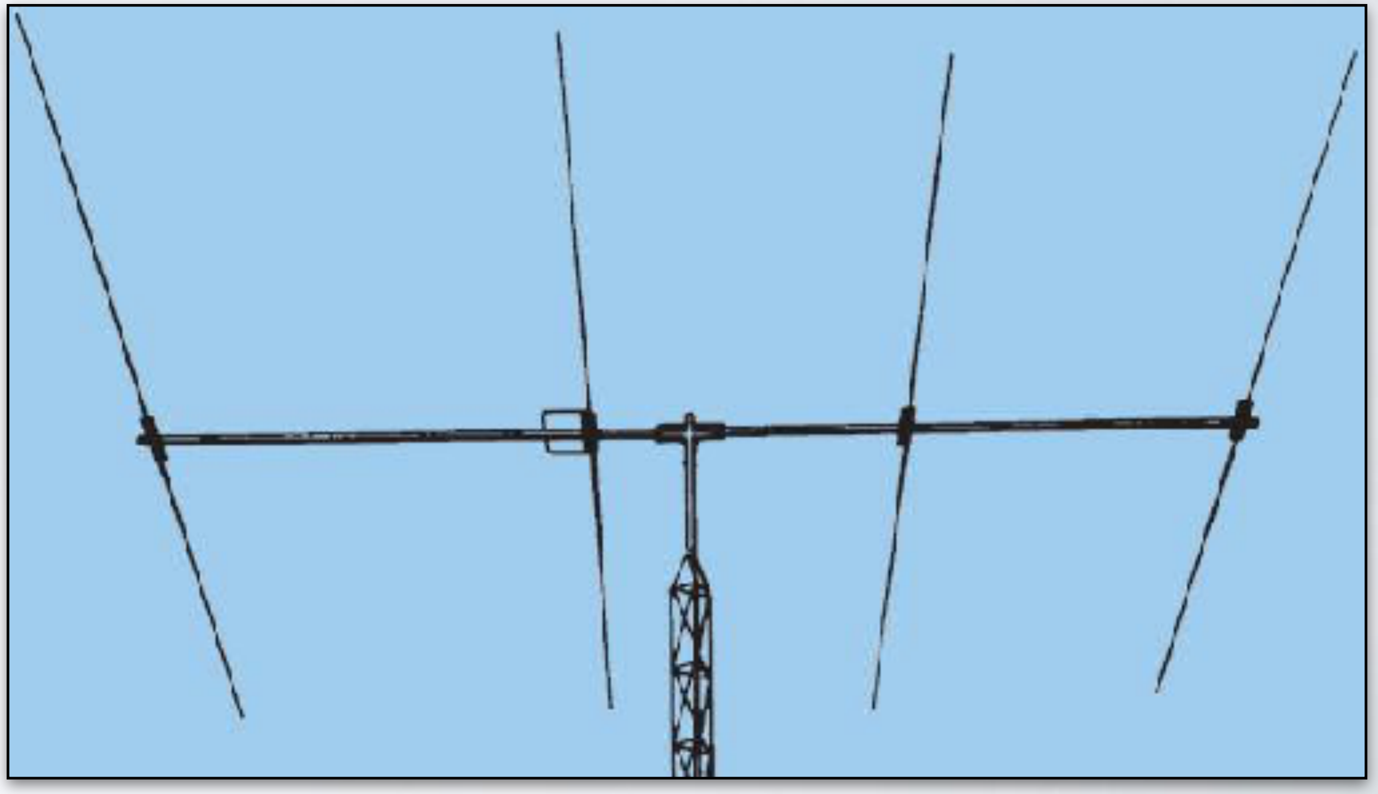

G5RV

- Variable gain with freq
- Variable R_{rad} with freq
- Height required for pattern
  - long but simple
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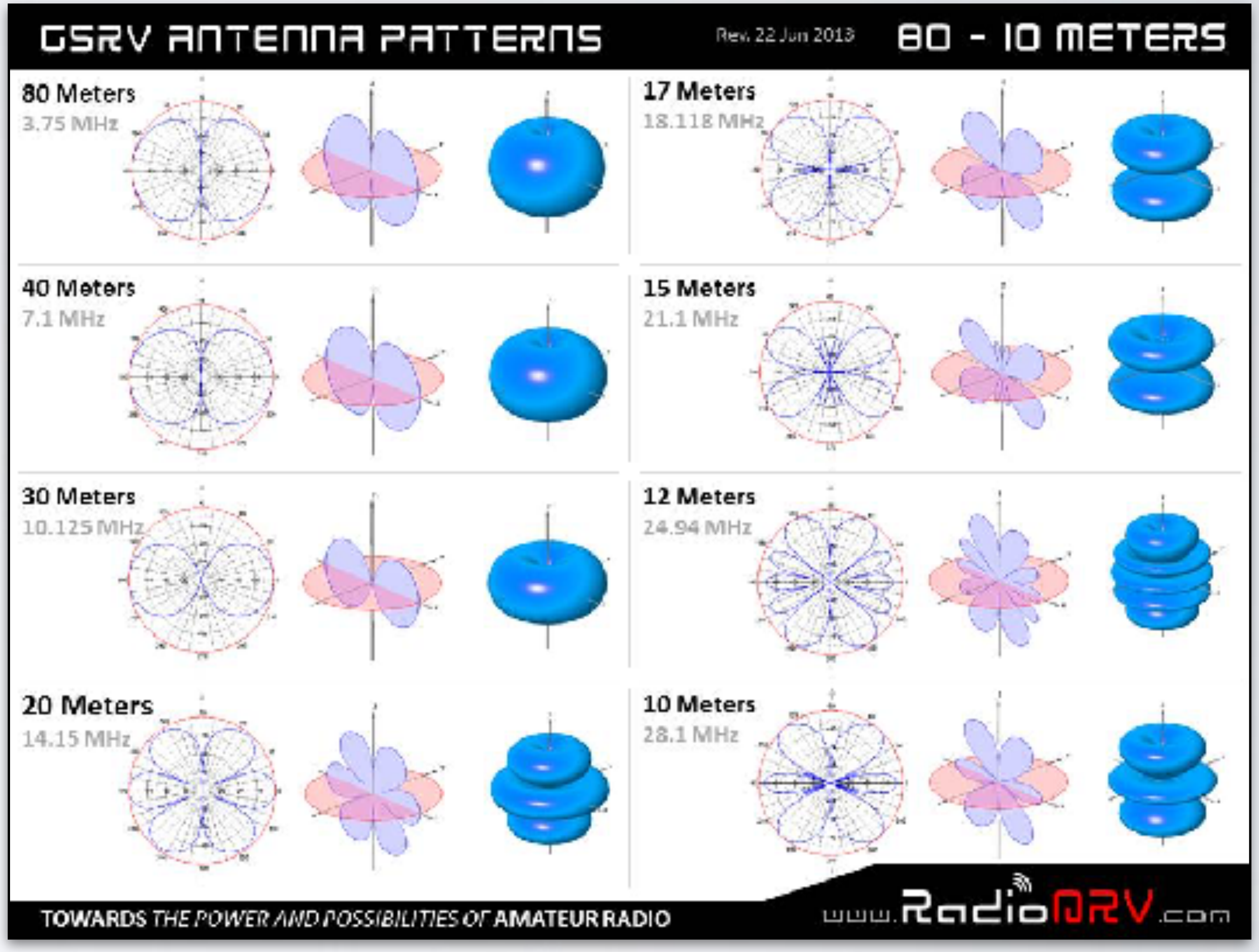

LARGE LOOP

- Some gain, like dipole
- High R_{rad} ~100 ohms
- Height required
  - depends on polarization
- Low Q
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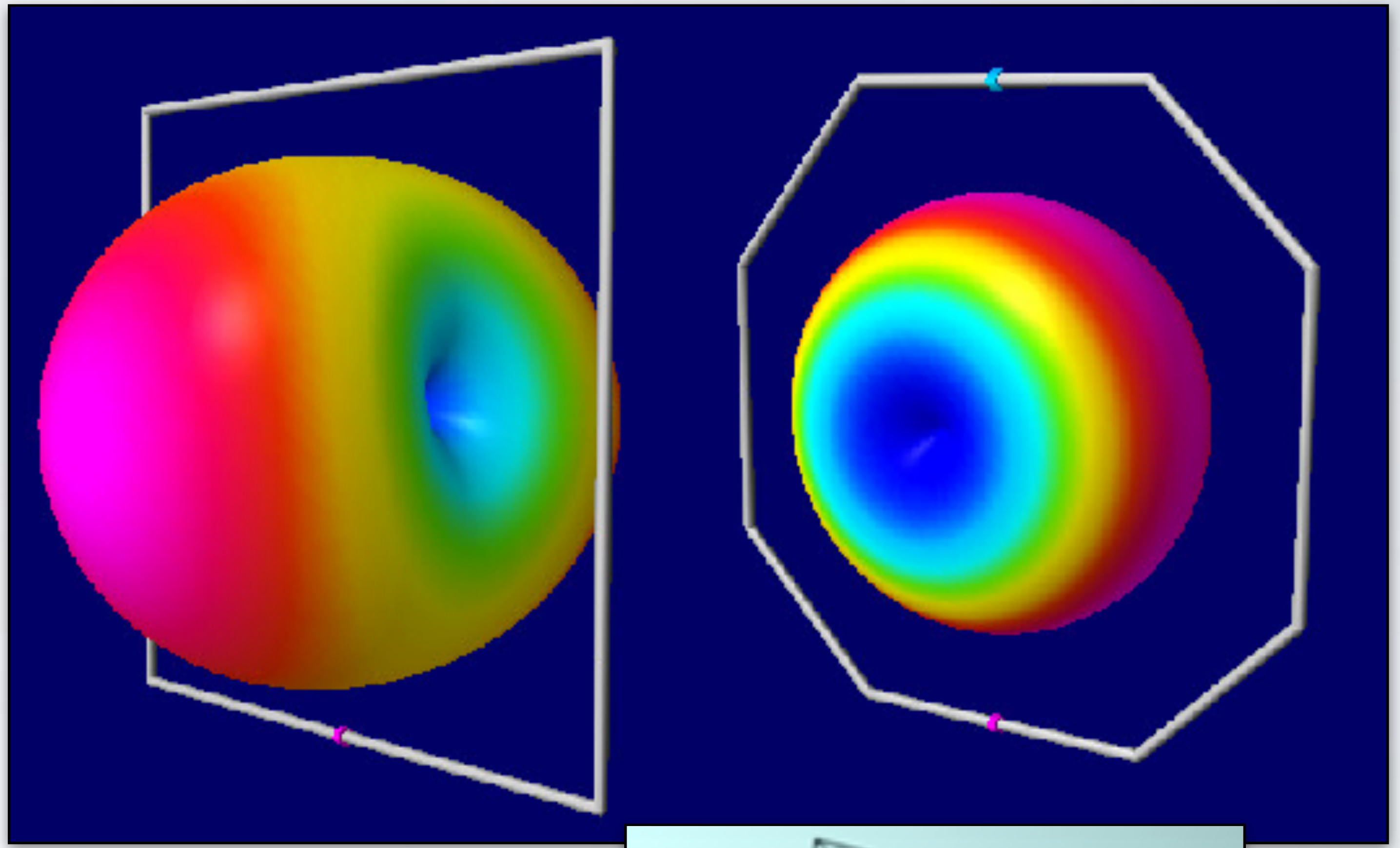

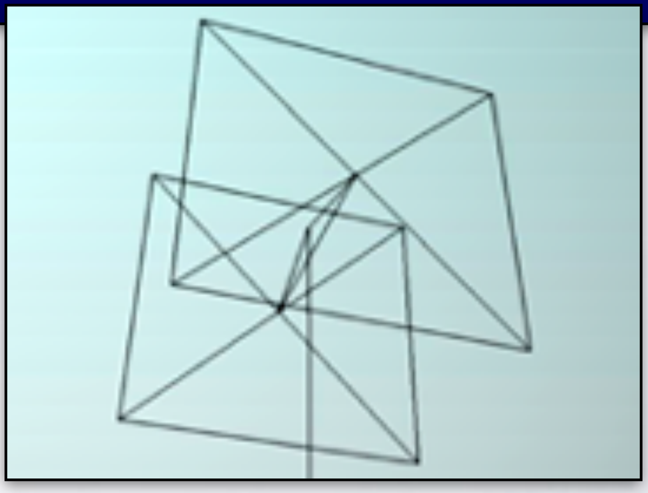

SMALL ‘MAGNETIC’ LOOP

- Some gain in loop plane
- Very low R_{rad} 0.001 Ohms
- Height not required
  - V polarized when upright
- Very high Q
- Sharp nulls in pattern

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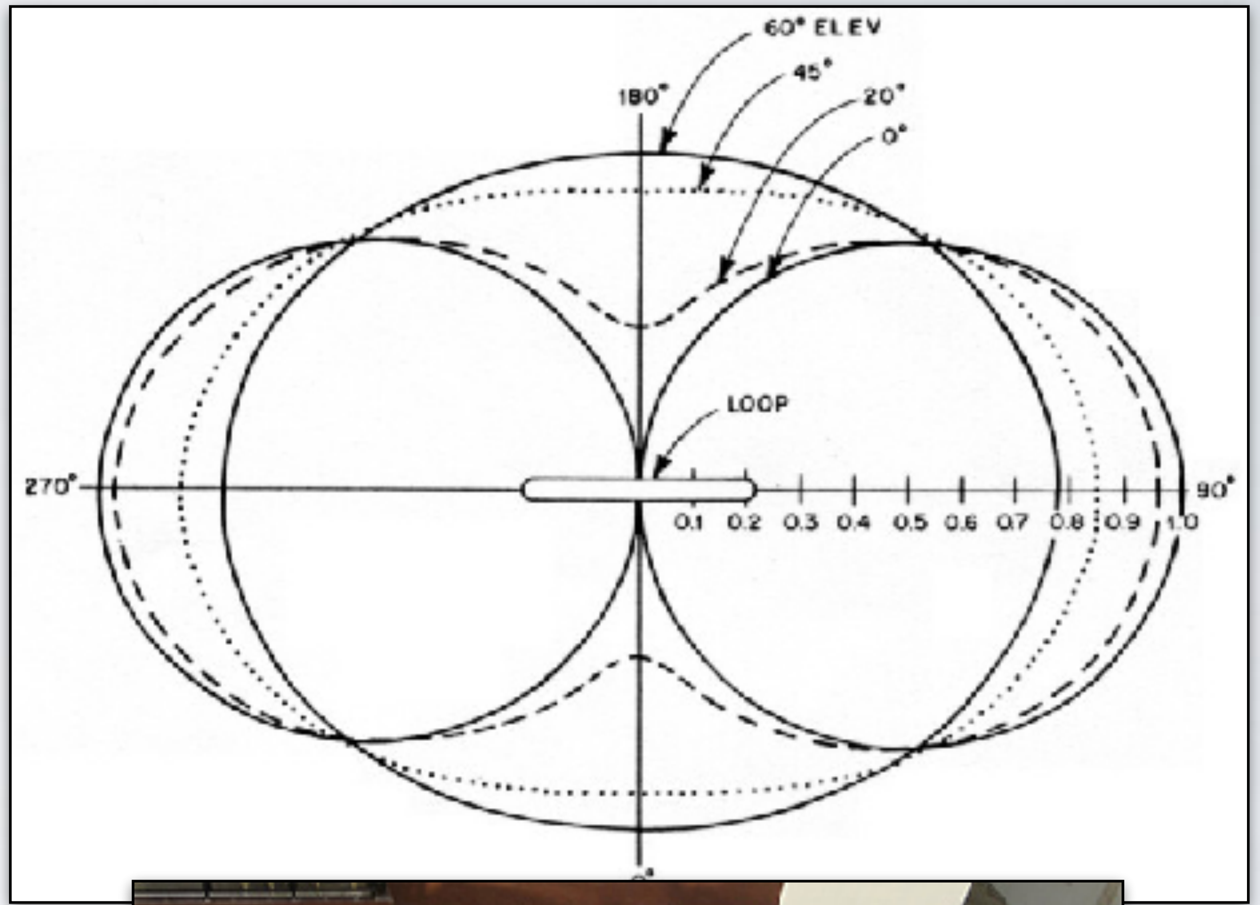

1/2 WAVE END FED

- Dipole-like gain (~2.2 dBi)
- High R_{rad} 72 ohms
  - feeding is ‘interesting’
- Height required if H
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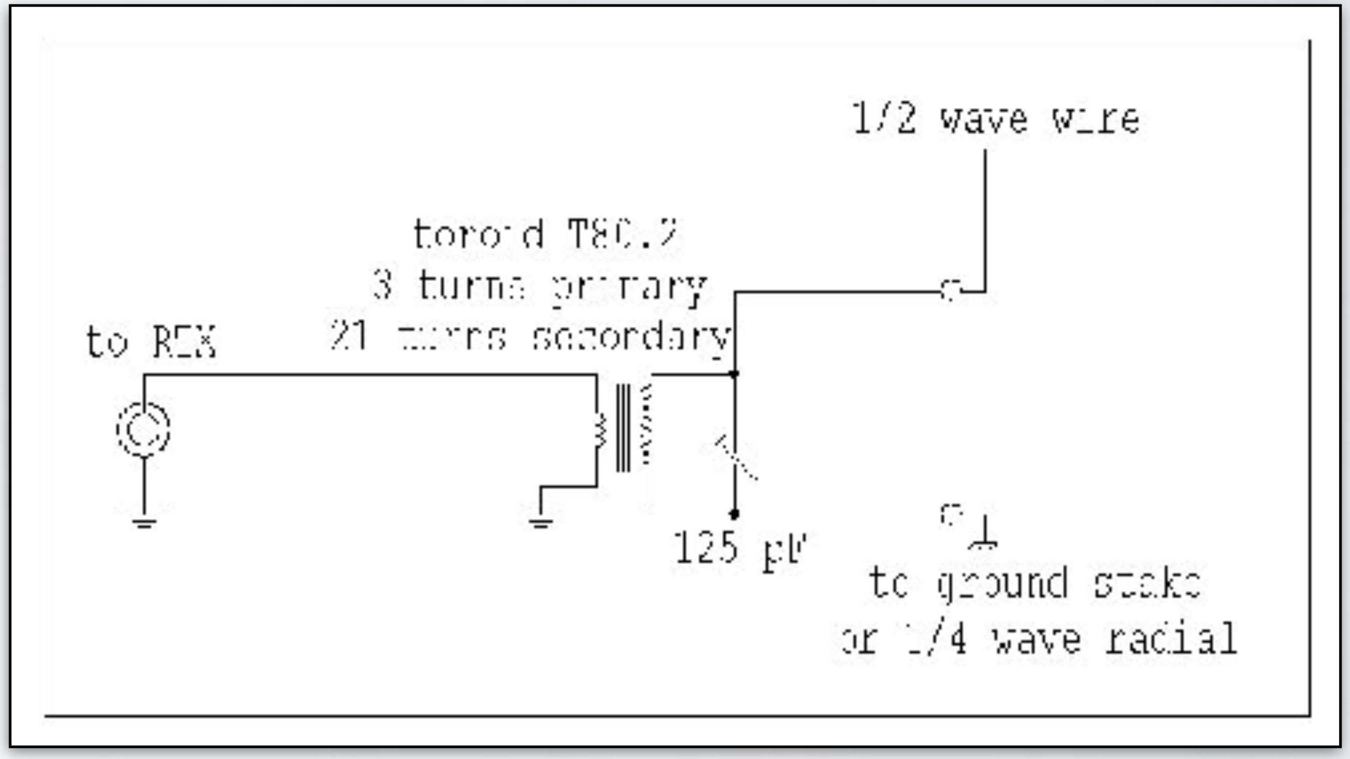

OCF DIPOLE

- Dipole gain - ~2.2 dBi
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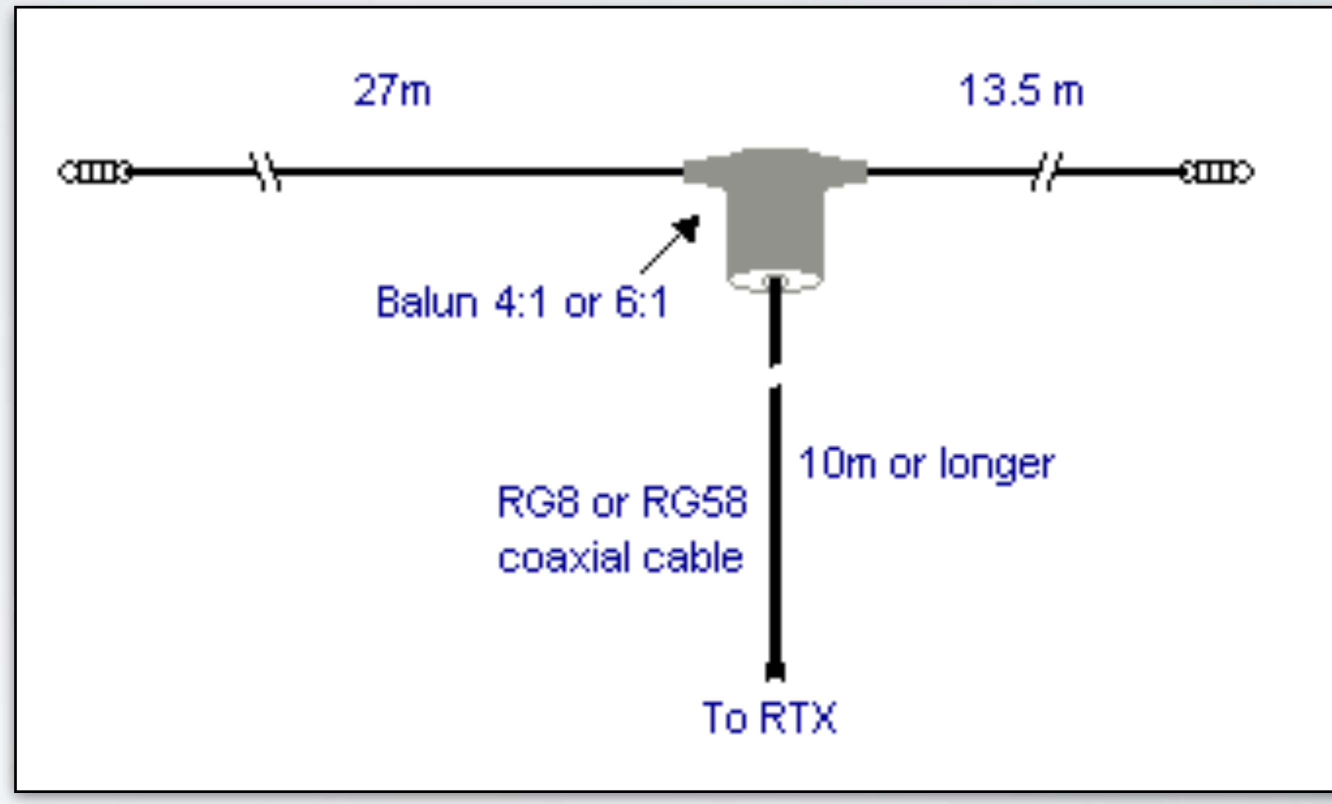

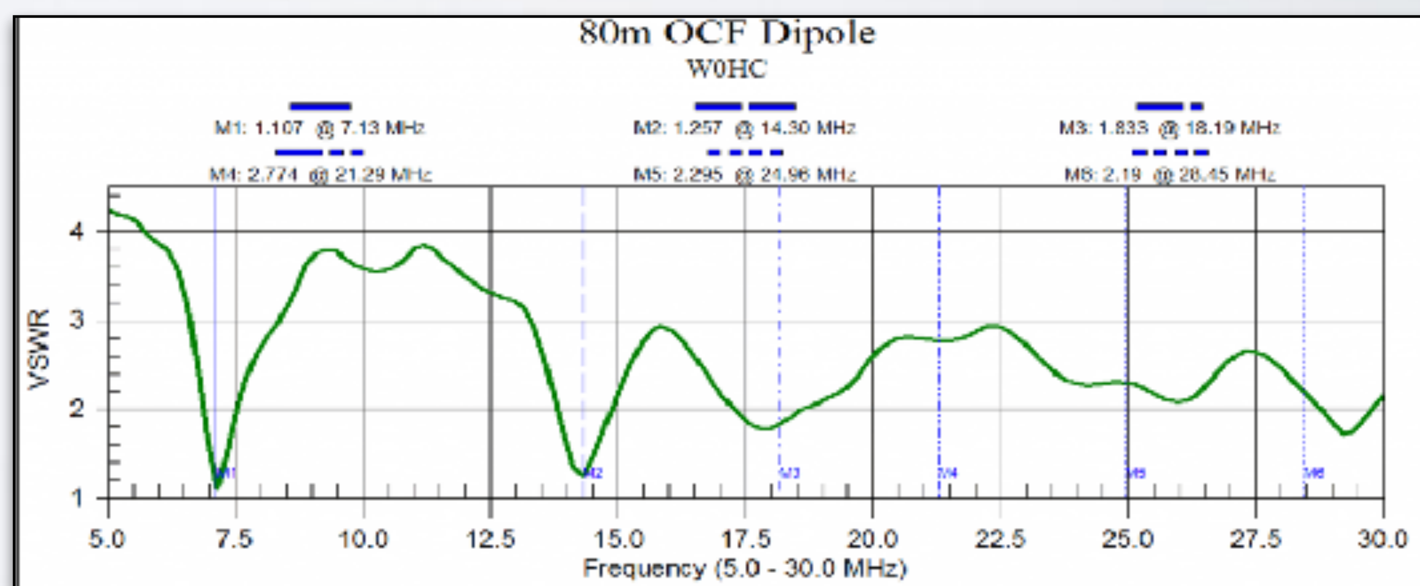

J-POLE

- Dipole gain
- High R_{rad} 72 ohms
- Height not required if V
  - long - 1/2 wave + match
- Medium-high Q with match
- Omnidirectional Az pattern
  - like vert dipole, higher El

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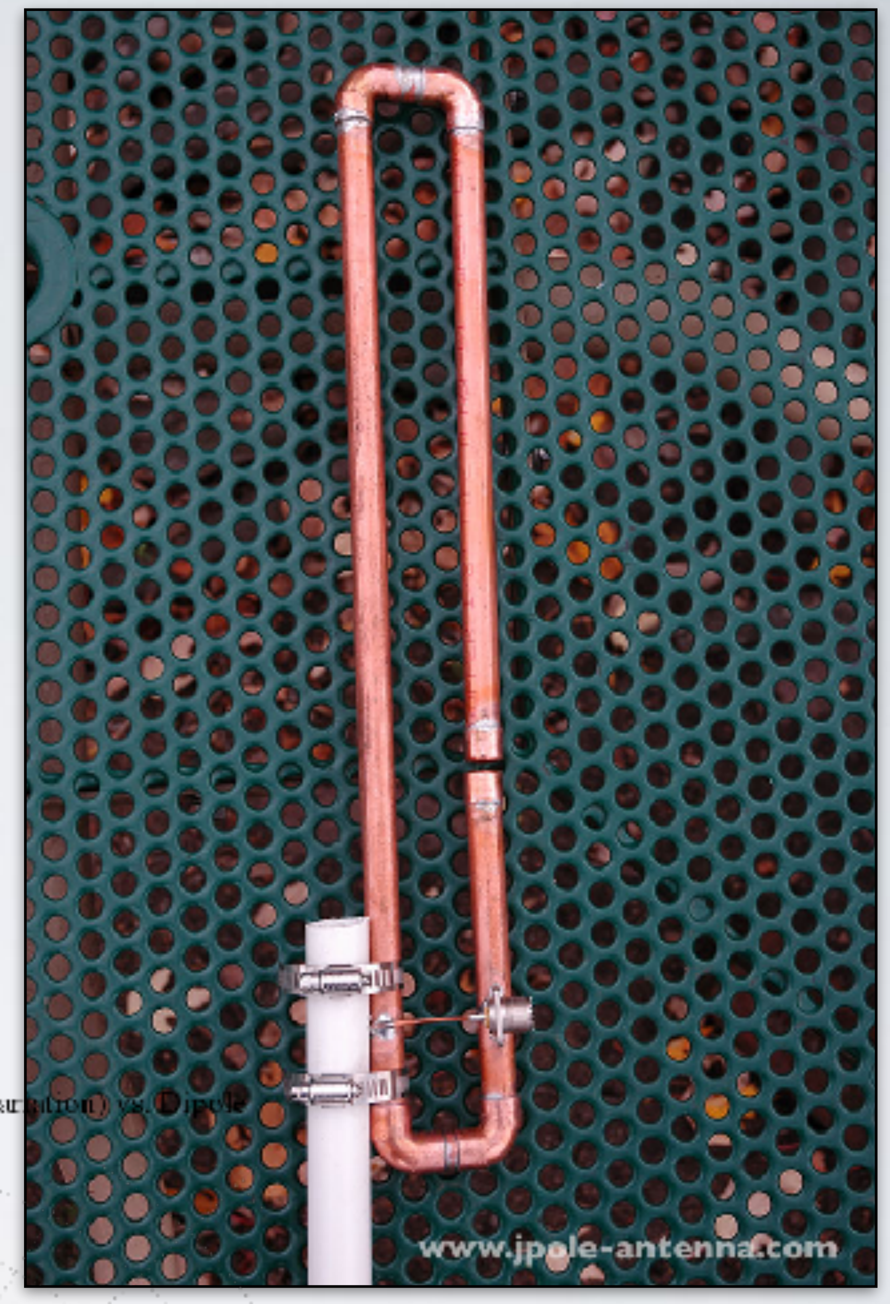

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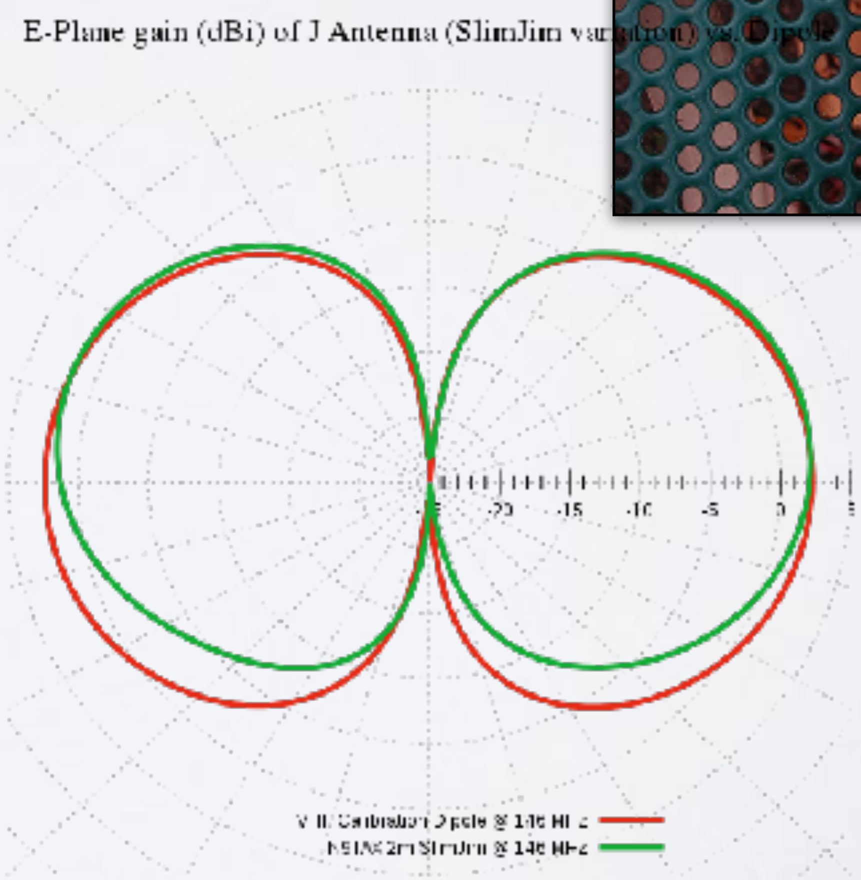

ISOTRON

- Claim: Poynting synthesis
- Classic snake oil
- Feed line is radiator
- ‘Antenna’ is a reactive termination
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WHAT MATTERS MOST

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- Efficiency
  - R_{rad}, R_{loss}, gain
- Convenience / deployment
  - structure, size
- Transmission
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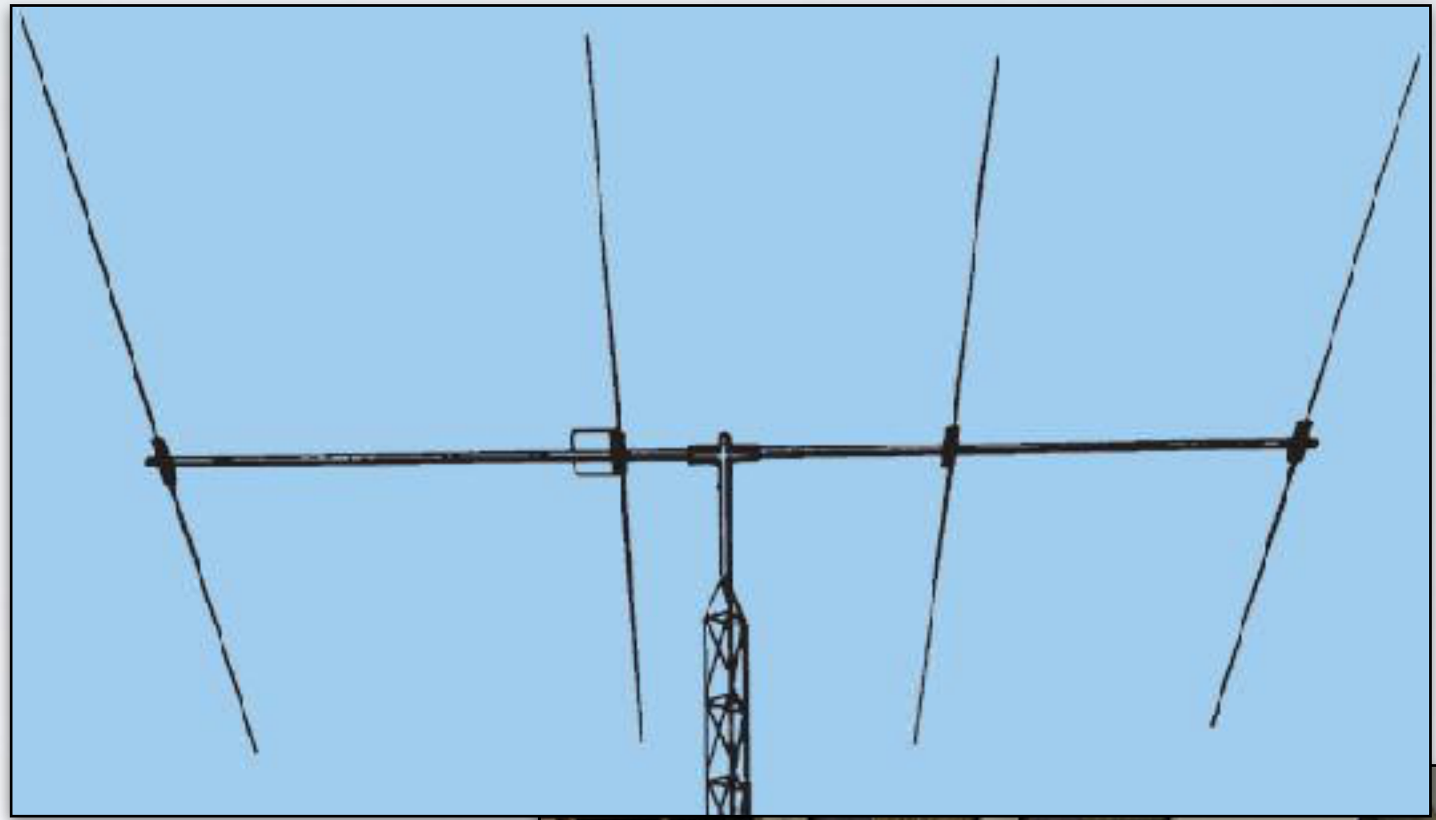

LEARNING MORE

- ARRL Antenna Book
- Wikipedia
  - aperture, gain, radiation resistance
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- Common sense
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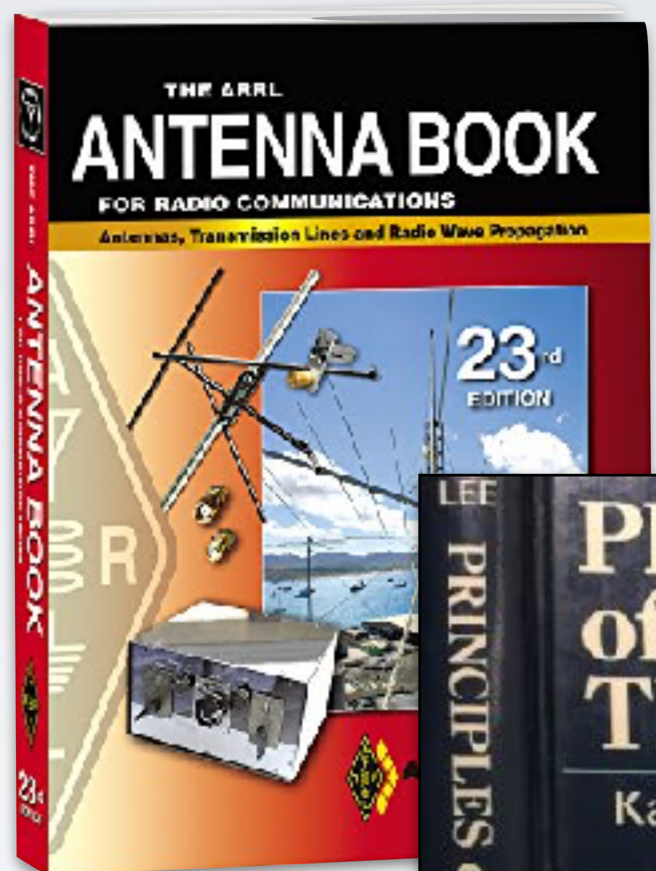

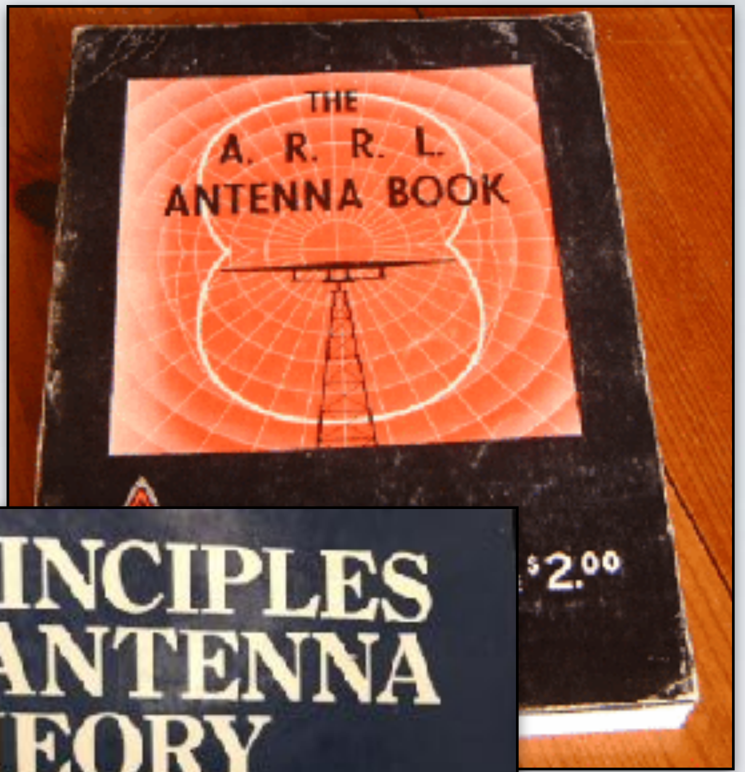

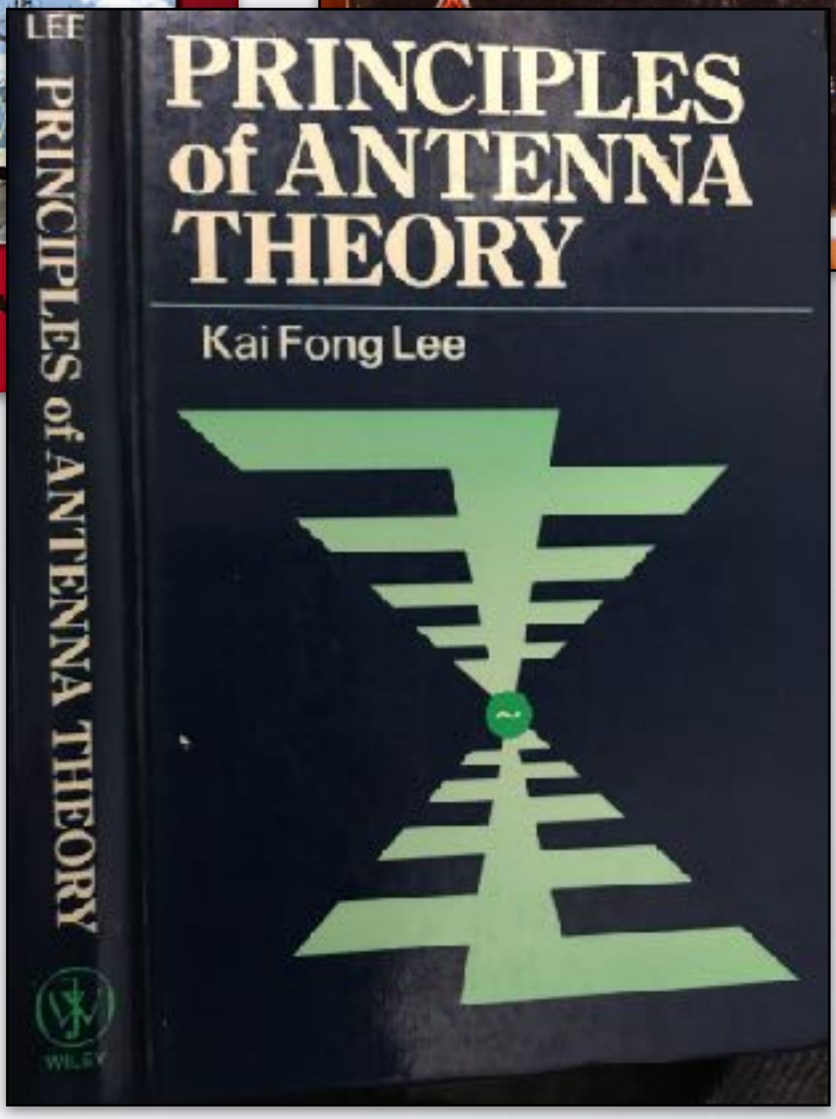

QUESTIONS?

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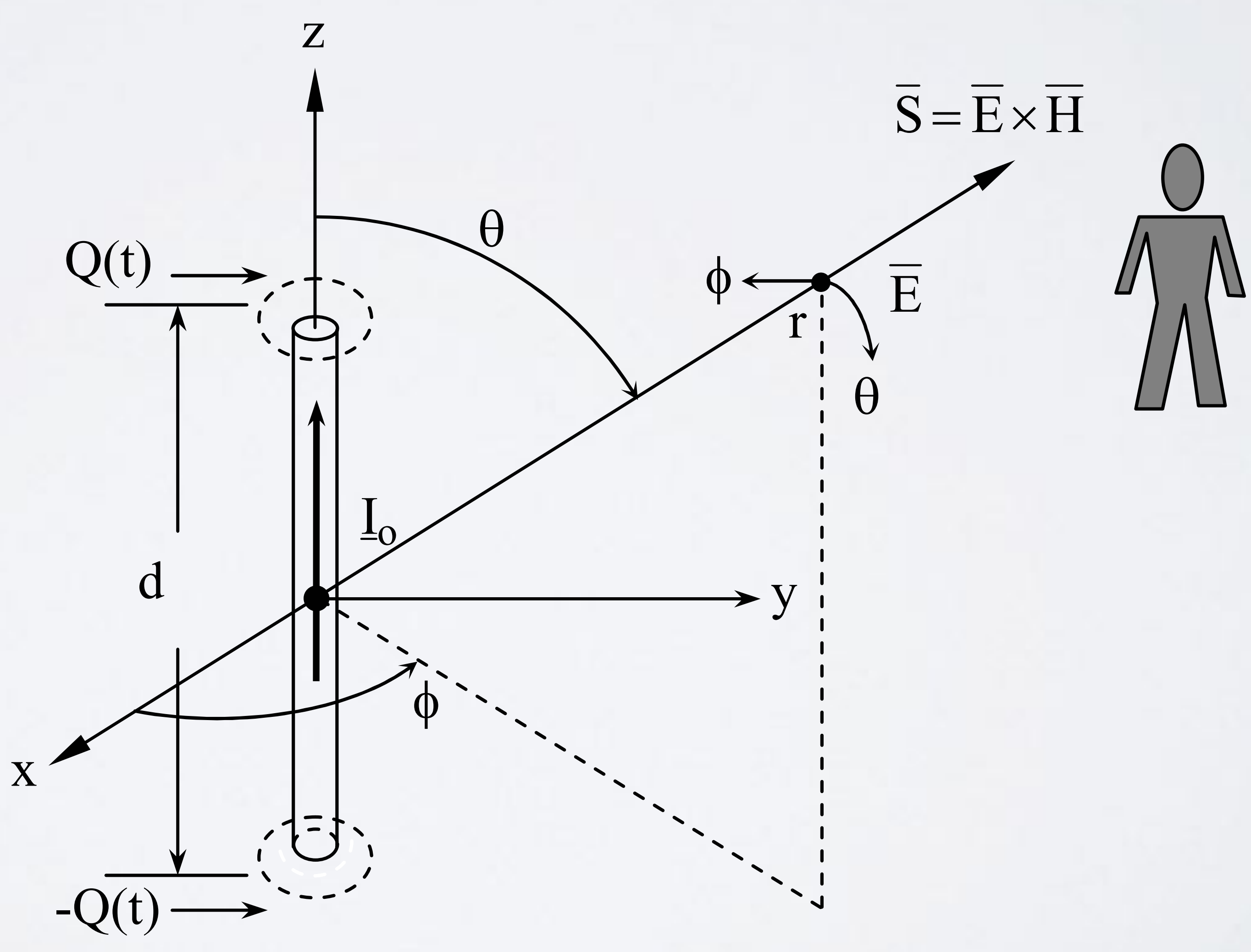

z
$\overline{S} = \overline{E} \times \overline{H}$
θ
Q(t)
ϕ
$\overline{E}$
r
θ
$\underline{I}_o$
d
y
ϕ
x
-Q(t)

THANK YOU!